GEOLOGICAL SURVEY OF CANADA
BULLETIN 396

CONTRIBUTIONS TO CANADIAN PALEONTOLOGY

Papers by
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I. Jin, W.G.E. Caldwell and B.S. Norford
A.F.H. Pedder
J. Ludvigsen, J.D. Keppie and P.S. Giles
J. Ludvigsen, M. Uyeno and A. Lachowsky
J.P. Pratten
J.W. Hay Cut
A.R. Sweet and R.M. Kalkreuth
R.J. Pattison

1989

Canada

THE ENERGY OF OUR RESOURCES

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PREFACE

From time to time it is appropriate to issue several short papers on paleontological topics as a single bulletin under the general title of *Contributions to Canadian Paleontology*. This bulletin contains ten papers describing a number of different groups of fossils. Such detailed studies provide the foundations essential to the refinement and application of schemes of biostratigraphic zonation that are fundamental to accurate stratigraphic interpretations of the sedimentary basins of Canada.

Elkanah A. Babcock
Assistant Deputy Minister
Geological Survey of Canada

PRÉFACE

Il convient de temps à autre de publier plusieurs courts documents sur la paléontologie en un seul bulletin sous le titre général de *Contributions to Canadian Paleontology*. Le présent bulletin contient dix documents décrivant différents groupes de fossiles. Ces études détaillées permettent d'établir les bases essentielles au perfectionnement et à l'application des schémas de zonation biostratigraphique qui sont fondamentales à une interprétation stratigraphique exacte des bassins sédimentaires du Canada.

Elkanah A. Babcock
Sous-ministre adjoint
Commission géologique du Canada

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Figure A. *Locality map for all papers.*

A LOWER MIDDLE ORDOVICIAN MICROFAUNA FROM OTTAWA, ONTARIO

M.J. Copeland[1], William G. Parkins[2] and Godfrey S. Nowlan[3]

Copeland, M.J., Parkins, W.G., and Nowlan, G.S., A Lower Middle Ordovician microfauna from Ottawa, Ontario. In Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 396, p. 1-19, 1989.

Abstract

Five species of phosphatized ostracodes were obtained from acid residues of samples from a thin (5 cm) phosphatic dolostone bed in the upper part of the Rockcliffe Formation east of the Canadian Forces Base Ottawa (North). This ostracode fauna is tentatively correlated with that from the Chazyan Stage of the Lake Champlain area, New York. A moderately diverse conodont fauna has been recovered from the same unit; it is dominated by specimens of *Erismodus* sp. cf. *E. typus* Branson and Mehl and *Phragmodus flexuosus* Moskalenko, which also indicate a Chazyan age for the sample.

Résumé

Cinq genres et espèces d'ostracodes phosphatisés ont été recueillis de résidus acides d'échantillons provenant d'une couche mince (5 cm) de dolomie phosphatique dans la partie supérieure de la formation de Rockcliffe à l'est de la base des Forces canadiennes à Ottawa (nord). Cette faune d'ostracodes a été temporairement corrélée à celle de l'étage chazyen de la zone du lac Champlain (New York). Une faune de conodontes raisonnablement variée a été recueillie dans la même unité; elle se compose surtout de *Erismodus* sp. cf. *E. typus* Branson et Mehl et *Phragmodus flexuosus* Moskalenko, qui établissent également l'âge chazyen de l'échantillon.

INTRODUCTION

A sequence of lower Middle Ordovician rocks is exposed in a north-facing escarpment east of the Canadian Forces Base Ottawa (North), commonly referred to as C.F.B. Rockcliffe. One section, 0.25 km east of the airbase (Fig. 1.1A) comprises about 18 m of the Rockcliffe Formation overlain by limestone that may be assigned either to the Chazyan St. Martin Formation or to the Pamelia Formation of the Black River Group. Fossils are generally rare in the Rockcliffe Formation and there are few beds in which the lithology is suitable for acid digestion. Ostracodes and conodonts were recovered from a sample of a 5 cm thick bed of phosphatic and dolomitic limestone, 3.6 m below the top of the Rockcliffe Formation (Fig. 1.1C; Rc-6 in Fig. 1.2). The ostracodes have been identified and described by M.J. Copeland and the conodonts by G.S. Nowlan. The sample was collected, processed and picked by W.G. Parkins, who contributed substantially to the stratigraphy and sedimentation parts of the manuscript.

STRATIGRAPHY

Raymond (1905a, b; 1912) assigned all the Middle Ordovician sandstone, shale and impure carbonate of the Chazy Series in the Ottawa area to the Aylmer Formation. The stratigraphic interval was reassessed by Wilson (1937, 1946) as two formations with a gradational and conformable contact relationship: a lower, mainly clastic Rockcliffe Formation with a type area in Rockcliffe Park just west of the airbase, and an upper, mainly carbonate St. Martin Formation with its type area some 200 km to the east. Because the section near the Rockcliffe airbase in Ottawa consists predominantly of clastic rocks, with minor and impure carbonate in the upper part of the sequence, we prefer to refer virtually the entire section to the Rockcliffe Formation following the recent usage of the Ontario Geological Survey (Williams and Telford, 1986). This usage essentially renames the Aylmer Formation of Raymond (1905a, b) as Rockcliffe. Williams and Telford (1986, p. 7) recognized two informal members in their Rockcliffe Formation, "in both of which interbedded quartz sandstone and shale occur, the upper member being distinguished by the presence of limestone and silty dolostone interbeds"; both members are readily recognized in the airbase section. The purer carbonates that form the ledge at the top of the section could belong to the St. Martin Formation but are better referred to the overlying Pamelia Formation. A sample from this unit was barren of conodonts.

The lower part of the section consists of interbedded dark olive-grey shale and fine quartzose to dolomitic sandstone (Fig. 1.2). Flaser bedding, ripple marks, crossbedding and load structures are common in the sandstone. Abundant trace fossils occur on some of the bedding surfaces in the shale units, but macrofossils are rare. The upper part is interbedded dark olive-grey to brown shale, locally dolomitic, with rare, impure, phosphatic limestone and silty dolostone. The limestone units are thin (typically less than 5 cm thick), medium to dark grey, and locally discontinuous. The dolostone beds are massive, medium grey, buff weathering, fine grained, and fracture conchoidally. Macrofossils occur rarely in the upper part of the section.

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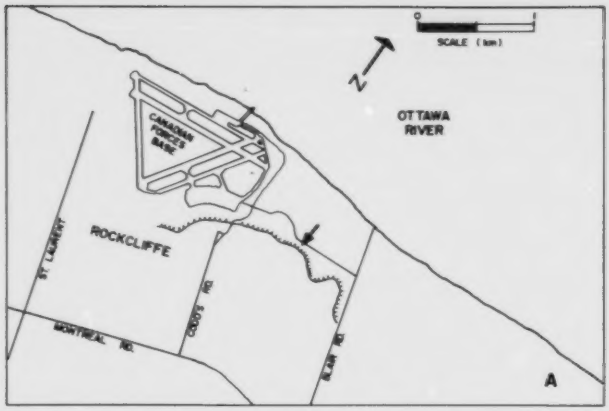

Figure 1.1A. *Location of section (black arrow) near Canadian Forces Base Rockcliffe, Ottawa, Ontario. Section is located at latitude 45°27'29"N, longitude 75°37'42"W on NTS sheet 31 G/05.*

SEDIMENTATION

The upper part of the Rockcliffe Formation in the section was deposited beyond the westernmost extension of the St. Martin carbonate facies. Strata unequivocally ascribable to the St. Martin facies occur 80 km east of Ottawa in the vicinity of Hawkesbury, Ontario, but the facies does not occur west of Ottawa. The upper part of the studied section is about 80 per cent shale, 10 per cent massive dolostone and 10 per cent phosphatic limestone.

An oriented thin section (Fig. 1.1B) through the 5 cm thick bed of microfossil-bearing, phosphatic limestone (GSC loc. 102169; Rc-6 of Fig. 1.2) shows at least three cycles of sedimentation. Within each, there is a basal layer (0.5 to 3 mm) of dolosiltite with abundant fragments of linguloid brachiopods oriented parallel to the bedding. This thin layer, lying on an irregular erosion surface, is interpreted as a lag deposit produced by storm or tidal action in relatively shallow water. The lag deposit is overlain by argillaceous dololutite (5 to 15 mm) with linguloid brachiopod fragments and randomly oriented disarticulated ostracodes, bivalves and

Figure 1.1B. *Oriented thin section of sampled bed (Rc-6; GSC loc. 102169). Broad white arrow indicates "up" direction; black arrow points to* **e**, *erosional surface;* **l** *lag deposit;* **m** *bioturbated micritic dolostone;* **p** *phosphate nodule;* **q** *quartz grain;* **r** *rhynchonellid brachiopod;* ***1.1C.*** *Section 0.5 km east of Canadian Forces Base Rockcliffe, Ottawa, Ontario. White arrow indicates sampled GSC loc. 102169, unit Rc-6. PF? indicates strata probably referable to the Pamelia Formation. White dashed line represents the base of unit Rc-18 above which the Rockcliffe Formation becomes more shaly and the first calcareous units appear.*

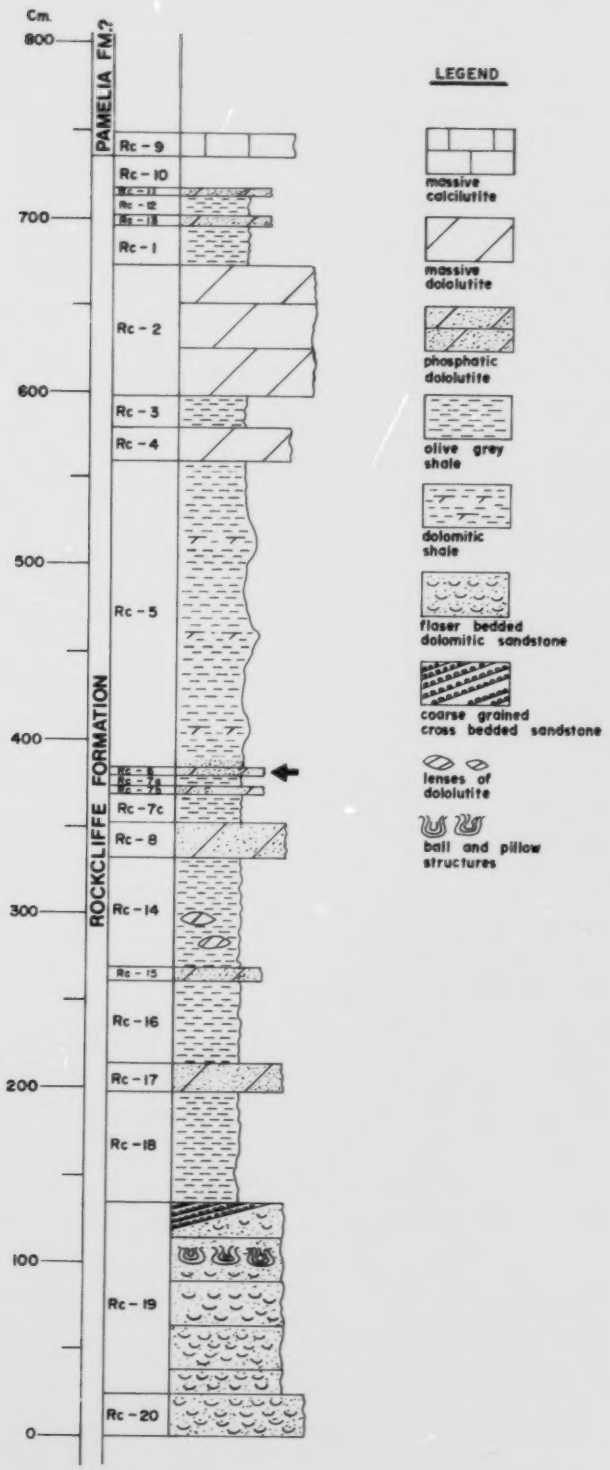

Figure 1.2. *Diagrammatic lithological representation of the section illustrated in Figure 1.1C. Black arrow indicates position of phosphatic dolostone bed Rc-6 (GSC loc. 102169).*

the brachiopod *Rostricellula*. This layer was deposited in quiet water. Bioturbation accounts for the disarticulation of the bivalved organisms and the underlying lag layer is penetrated and disrupted locally. The dololutite layer is truncated abruptly by an irregular erosion surface on which the lag layer of the next sedimentary cycle rests. Well rounded and frosted quartz grains, up to 2 mm in diameter, are found throughout the bed, but are concentrated in the lag deposits.

Rounded to irregularly shaped phosphatic nodules up to 5 mm long are scattered randomly throughout the sample and constitute 5 to 10 per cent of the rock. They contain angular silt- and mud-sized grains of dolomite and are considered to be post-depositional in origin. Many microfossils, replaced by phosphate, acted as nuclei for the formation of these nodules.

Disarticulated valves of *Rostricellula orientalis* and linguloid brachiopod fragments are common in this bed. The microfauna consists of moderately abundant conodonts and rarer ostracodes, bivalves, gastropods and curved, tubular cones of uncertain affinity. Some of the phosphatic blebs etched from the bed are clearly coprolites. Conodonts and linguloid brachiopods were originally composed of calcium phosphate, but the shells of most of the other microfauna have been replaced and casts by calcium phosphate. A few microfossils have been pyritized.

During late Chazyan time, the Ottawa Valley region was a shallow embayment on the Precambrian Shield of an epicontinental sea extending from a depositional basin to the east and southeast. In the western part of the embayment, sandstone and shale were deposited; to the east, near present day Ottawa, some impure carbonates were deposited locally. During much of Chazy time in the Ottawa area, fine clastic sediments were deposited under shallow water conditions. Grains of quartz sand were blown into the basin, possibly from sand dunes bordering the embayment. During relatively brief periods clastic sedimentation slowed or ceased, and dolomitic sand and silt were deposited. Periodic storms eroded the soft mud substrate, winnowing the soft mud and aligning fragments of linguloid brachipods that had been transported from a higher energy clastic environment, presumably to the west. There is no evidence that energy levels were sufficiently high at the depositional site to break these linguloids, and the ostracode and rhynchonellid brachipod valves are mostly complete. Somewhat deeper water conditions may have been present to the east in the area of predominantly limestone deposition toward Montreal.

Gastropods, rhynchonellid brachipods, ostracodes and conodont-bearing organisms lived on or above the sediment surface. The bivalves and curved tubular conical shelled organisms of uncertain affinity may have been infaunal organisms. With the exception of the brachiopod *Rostricellula orientalis*, individuals in the fauna are small to microscopic.

PALEONTOLOGY

Ostracodes

Five taxa are present: *Lomatobolbina ottawaensis* n. sp., *Eurychilina placida* Swain (previously reported from the Chazy Group of Valcour Island, New York), *Conchoprimitia*? sp., *Pseudulrichia*? sp. and *Sigmobolbina* sp. Correlation is with the upper part of the Chazyan Stage but cannot be further refined.

Basal sandstone and shale and overlying limestone strata of Chazyan age in the Montreal, Quebec, area are referred to the Laval Formation, of which the St. Martin Member is the upper unit. Clark (1972) and Hofmann (1963, after Carter, 1957) list 10 genera of Ostracoda from the Laval, nine of which are indicated by Carter as occurring in the St. Martin Member. At Montreal the fauna consists of leperditicopes, palaeocopes and podocopes, but between Ottawa and Montreal only leperditicopes have been reported, notably from the vicinity of Hawkesbury and nearby l'Orignal, Ontario (Jones, 1891; Raymond, 1906). This may be due to collecting bias because of the large size of leperditicope specimens and the lack of favourable lithotypes from which to obtain non-leperditicopid specimens by conventional methods. It is usually considered that leperditicope ostracodes inhabited a nearshore, tidal to possibly brackish environment, but early leperditicopes (and these from the Chazy are among the earliest known) may have inhabited a more marine environment than their later Paleozoic representatives.

Conodonts

One sample (GSC loc. 102169, Rc-6, Fig. 2) weighing about 1 kg was processed for conodonts at the University of Ottawa by W.G. Parkins. Over 250 specimens were recovered from a large heavy residue that includes substantial phosphatic material. The conodont Colour Alteration Index (CAI) is 2.5, indicating heating of the strata to between 100° and 155°C. Legall et al. (1982) and Nowlan and Barnes (1987) have suggested that the unexpectedly high thermal level of strata in the Ottawa – Montreal region is the result of the passage of a Mesozoic hotspot and is not due to sedimentary burial. Preservation is good but most specimens are fragmentary. Taxomonic descriptions are presented for the six species marked by an asterisk in the list below. The remaining eight are merely illustrated or listed.

Cardiodella tumidus (Branson and Mehl) (not illustrated; 8 specimens)
Cardiodella sp. (not illustrated; 2 specimens)
* *Coleodus pectiniformis* Youngquist and Cullison (Pl. 1.4, figs. 8, 10; 5 specimens)
Curtognathus typa Branson and Mehl (not illustrated; 13 specimens)
* *Erismodus* sp. cf. *E. typus* Branson and Mehl (Pl. 1.4, figs. 2-4, 6, 7, 9; 106 specimens)
Evencodus? sp. (not illustrated; 3 specimens)
* *Oneotodus*? sp. cf. *O.*? *ovatus* (Stauffer) (Pl. 1.4, fig. 1; 2 specimens)
* *Phragmodus flexuosus* Moskalenko (Pl. 1.3, figs. 4, 5, 7-13; 227 specimens
* *Plectodina*? *ctenulata* (Youngquist and Cullison) (Pl. 1.3, figs. 1, 3, 6; 25 specimens)
Polycaulodus bidentatus Branson and Mehl (Pl. 1.4, fig. 11; 15 specimens)
P. gracilis Youngquist and Cullison (Pl. 1.4, fig. 5; 8 specimens)
P. inclinatus Branson and Mehl (not illustrated; 10 specimens)
* *Trigonodus* sp. cf. *T. sinuosus* (Mound) (Pl. 1.4, fig. 12; 12 specimens)
Trucherognathus distorta Branson and Mehl (Pl. 1.3, fig. 14; 6 specimens)

This fauna is numerically dominated by specimens of *Phragmodus flexuosus*, which constitutes 50 per cent of the fauna and is the most biostratigraphically diagnostic form. First described by Moskalenko (1973) from the Volginsky Horizon of the Siberian Platform, it has been recognized subsequenly that, although most of the elements of this species are readily identifiable, the apparatus is complex and has variable morphology. Ethington and Clark (1982) provided a detailed analysis of the taxonomic development of its elements and recognized two distinct North American species embraced by the original concept of *P. flexuosus*. Bauer (1987) has discussed these further, pointing out that one form has a cyrtoniodiform M (*e*) element, and has been generally accepted as true *P. flexuosus*, whereas the other has an oistodontiform M element (*Phragmodus* n. sp. of Harris et al., 1979). The latter form seems to appear earlier, at least in Nevada, where it first occurs with *Eoplacognathus suecicus* and is succeeded by true *P. flexuosus*, which first occurs with *Eoplacognathus reclinatus* and *E. foliaceous* (Harris et al., 1979).

Bauer (1987) distinguished two morphotypes of true *P. flexuosus*, an older form with undifferentiated P (*f* and *g*) elements readily distinguishable on the basis of the angle between the anterior and anterolateral processes. The specimens from the Rockcliffe Formation are clearly assignable to morphotype A, the younger form, which is known from the upper part of the McLish Formation, Tulip Creek Formation and from the lower part of the Bromide Formation in the Arbuckle Mountains of Oklahoma (Bauer, 1987). *Phragmodus flexuosus* is also known from the Lenoir Limestone and Holston Formation of Tennessee (Bergstrom and Carnes, 1976), the Chazy Group of New York (Raring, 1972), and Antelope Valley Limestone of Nevada (Harris et al., 1979) and the Sunblood and Esbataottine formations of the District of Mackenzie (Tipnis et al., 1978). Similar, or possibly conspecific, elements are present in the Canning Basin of Australia (Watson, 1984).

The unravelling of the taxonomic complexities of *P. flexuosus* is of potential importance to Middle Ordovician biostratigraphy. If it can be demonstrated that the apparatus bearing the oistodontiform element consistently occurs earlier than true *P. flexuosus* and that Bauer's two morphotypes appear in stratigraphic sequence, then there is potential for a useful tripartite biostratigraphic division of the range of elements formerly considered to belong to *P. flexuosus* in a broad sense.

However, factors other than time that could affect the distribution of these taxa need to be considered. It may be that ecological factors play a major role, rendering the species unsatisfactory for biostratigraphic purposes. The Chazyan Mingan Formation on the Mingan Islands, Quebec (Nowlan, 1981), contains elements originally ascribed to *P. flexuosus* with both geniculate coniform and cyrtoniodiform elements. The top of the Mingan Formation has yielded *Cahabagnathus chazyensis*, suggesting a mid-Chazyan upper limit for the unit (Nowlan, 1981). These occurrences may indicate that the strata were deposited at the time of biostratigraphic overlap of the two species or that there is an ecological overlap of contemporaneous taxa.

The other dominant species in the Rockcliffe collection is *Erismodus* sp. cf. *E. typus*. *Erismodus typus* itself is not well understood taxonomically. Its paleogeographic and biostratigraphic ranges are difficult to determine, but it is a hyaline species usually occurring in restricted shallow water facies. Its presence, together with several species of neurodont genera (*Curtognathus*, *Polycaulodus* and *Trucherognathus*) in this sample indicates a shallow water environment.

The other taxa present in the sample provide little biostratigraphic precision. Well preserved specimens of *Coleodus pectiniformis* are of some interest because the

taxon has not been reported since its description from the Dutchtown Formation in Missouri (Youngquist and Cullison, 1946).

The conodont fauna is of North American Midcontinent Province affinity and contains no representatives of the North Atlantic Province, such as *Eoplacognathus* and *Cahabagnathus*, which could have provided additional, more precise biostratigraphic information. Species of North Atlantic Province affinity are common in sediments of Chazyan age deposited in settings marginal to the North American craton in the southern Appalachians (e.g., Bergström and Carnes, 1976) and in Nevada (Harris et al., 1979).

SYSTEMATIC PALEONTOLOGY

Subclass OSTRACODA Latreille, 1806

Order PALAEOCOPIDA Henningsmoen, 1953

Superfamily DREPANELLACEA Ulrich and Bassler, 1923

Family RICHINIDAE? Scott, 1961

Genus *Pseudulrichia*? Schmidt, 1942

Type species. *Leperditia bivertex* Ulrich, 1879.

Pseudulrichia? sp.

Plate 1.2, figures 5, 6

Description. Only steinkerns are available for study. Valves generally amplete, anterior and posterior margins evenly rounded. Hinge about two thirds greatest length. Surface of valves with two dorsomedian lobes separated by S2, merging ventrally with each other and with the elevated ventromedian valve surface. The anterior lobe is somewhat node-like and more prominent than the posterior, more vertically elongate lobe. One specimen (Plate 1.2, figure 6) shows a near marginal row of pits.

Dimensions. Figured specimen GSC 85998: length 1.5 mm, height 0.9 mm.

Remarks. Because of the type of preservation of the specimens, the exact nature of the external lobation may only be assumed. The specimens are only tentatively assigned because of the near marginal row of pits on one left valve. The specimens are steinkerns and these pits must represent internal, near marginal spines or stop pegs against which the right valve closed. This condition has not previously been recorded within the Richinidae.

Superfamily HOLLINACEA Swartz, 1936

Family EURYCHILINIDAE Ulrich and Bassler, 1923

Genus *Eurychilina* Ulrich, 1889

Type species. *Eurychilina reticulata* Ulrich, 1889.

Eurychilina placida Swain, 1962

Plate 1.2, figures 1-4

Eurychilina placida Swain, 1962, p. 730, Plate 109, figures 7a-f.

Remarks. The specimens agree most closely with the specimen from the Crown Point Formation, Valcour Island, New York shown by Swain (1962, Pl. 109, fig. 7c) in that S2 and L2 are somewhat ill-defined, and the velar structure is a row of small spinose projections. Swain commented that this specimen is small (length approx. 0.64 mm), as are the present specimens. Possibly the poor development of S2 and L2 is a juvenile characteristic of the species.

Dimensions. Hypotype GSC 85994: length 0.62 mm, height 0.40 mm.

Family SIGMOOPSIDAE Henningsmoen, 1953

Genus *Lomatobolbina* Jaanusson, 1957

Type species. *Ctenobolbina mammillata* Thorslund, 1940.

Lomatobolbina ottawaensis Copeland sp. nov.

Plate 1.1, figures 7, 8

Description. Valves preplete, hinge about three quarters valve length, cardinal angles more than 90 degrees, posterior margin more broadly curved than anterior margin. Unisulcate, S2 long, sigmoidal ventrally, almost reaching the histium, L2 an elevated node not fused with L1. L3 low, except posteroventral of S2 where it is inflated and may be produced into a node. Tecnomorphs with a faint histial ridge, without a velar structure; heteromorphs with a relatively broad, planar histium nearly confluent with the domicilial surface, without velar structure. Surface smooth to slightly granular.

Dimensions. Holotype GSC 85991: length 0.8 mm, height 0.5 mm.

Remarks. This species differs from *Lomatobolbina* sp. of Spjeldnaes (1963) in lateral outline and *Lomatobolbina* sp. nov. 1 of Siveter (1978, p. 48) from the Llandeilo Series of Wales, in that that species appears to have "a faintly developed velar ridge". Also, the heteromorphic specimen figured by Siveter (1978, Pl. 1, fig. 11) has a broader, more convex dolonal type of histium than the present species.

Genus *Sigmobolbina* Henningsmoen, 1953

Type species. *Entomis oblonga* var. *Kuckersiana* Bonnema, 1909.

Sigmobolbina sp.

Plate 1.1, figures 1-6

Description. Valves amplete to slightly preplete, hinge long, about three quarters greatest length, posterior margin more broadly curved than anterior, venter nearly straight. Unisulcate, S2 strong, sigmoidal, extending from dorsum to

velum. L2 a prominent node fused with L1. L3 broad, low except posteroventral of S2 where the valve is inflated but not developed as a node or a spine. Velar structure on tecnomorphs a thin, narrow ridge. No heteromorphic specimens available.

Dimensions. Figured specimen GSC 85986: length 0.9 mm, height 0.45 mm.

Remarks. This species agrees in many respects with the tecnomorphic specimen of *S. sigmoidea* Jaanusson from the Crassicauda Limestone of Sweden figured by Jaanusson (1957, Pl. XI, fig. 20). S2 of that species, as well as the present species, is deep, strongly sigmoidal and inclined anteroventrally and the tecnomorphic velar structure is a thin ridge. Without heteromorphic specimens being available, no specific determination is possible.

Superfamily LEPERDITELLACEA Ulrich and Bassler, 1906

Family LEPERDITELLIDAE Ulrich and Bassler, 1906

Genus *Conchoprimitia* Öpik, 1935

Type species. Conchoprimitia gammae Öpik, 1935.

Conchoprimitia sp.

Plate 1.2, figures 7, 8

Description. Valves subelliptical with long, straight hinge, cardinal angles rounded. Valve amplete to slightly preplete. Surface rising smoothly from all margins, without sulcation or lobation. Faint indication of a near median, dorsal sulcus may be found on the internal surface. No marginal structure.

Dimensions. Figured specimen GSC 85999: length 0.8 mm, height 0.4 mm.

Remarks. No specimens were found with retained moults, consequently the generic designation is questioned. Schallreuter (1980, p. 21) erected a genus, *Conchoprimitiella*, for specimens similar to these and included *Conchoprimitia* sp. of Siveter (1978, p. 45) from the Llandeilo Series of Wales. Cast off moults of *Conchoprimitia* would have all the features ascribed to *Conchoprimitiella*. Until more conclusive evidence of generic differentiation is found, the older generic terminology is used here.

Phylum CONODONTA Pander, 1856

Class CONODONTATA Pander, 1856

Order CONODONTOPHORIDA Eichenberg, 1930

Genus *Coleodus* Branson and Mehl, 1933

Type species. Coleodus simplex Branson and Mehl.

Coleodus pectiniformis Youngquist and Cullison, 1946

Plate 1.4, figures 8, 10

Coleodus pectiniformis Youngquist and Cullison, 1946, p. 581, Pl. 89, figs. 7, 19.

Remarks. Specimens of *Coleodus*, including those of the type species, are usually highly fragmentary. However, *C. pectiniformis* was erected based on an extremely well preserved holotype. The specimens recovered from the Rockcliffe Formation are also well preserved and show the features that serve to distinguish *C. pectiniformis* from *C. simplex* Branson and Mehl, namely the more arcuate and posteriorly reclined denticles and arched aboral margin. In the larger specimen figured, the denticles are fused along most of their length, with denticle margins extended onto the blade as delicate grooves. A smaller specimen (Pl. 1.4, fig. 10) shows discrete, needle-like denticles. Both illustrated specimens have a preserved basal filling.

Types. Hypotypes, GSC 90633, 90634.

Material. 5 specimens.

Genus *Erismodus* Branson and Mehl, 1933

Type species. Erismodus typus Branson and Mehl.

Remarks. The revised generic diagnosis of Sweet (1982, p. 1040) is followed herein, although it is difficult to recognize clearly distinguishable Pa (*f*) and Pb (*g*) elements in the material at hand.

Erismodus sp. cf. *E. typus* Branson and Mehl, 1933

Plate 1.4, figures 2-4, 6, 7, 9

cf. *Erismodus typus* Branson and Mehl, 1933, p. 25, Pl. 1, figs. 9, 11, 12; Andrews, 1967, p. 891, Pl. 112, figs. 9-11, 18, Pl. 114, fig. 21; ? An et al., 1983, p. 95, Pl. 32, figs. 18, 19.

cf. *Erismodus asymmetricus* (Branson and Mehl). Andrews, 1967, p. 893-894, Pl. 112, figs. 1, 3, 6, 7, 14, 17, Pl. 113, fig. 1, Pl. 114, figs. 7, 9, 13.

cf. *Erismodus symmetricus* Branson and Mehl. Andrews, 1967, Pl. 112, figs. 4, 5, 13, 16, 21, Pl. 113, fig. 7, Pl. 114, figs. 4, 18, 24.

cf. *Erismodus gracilis* Branson and Mehl. Andrews, 1967, p. 894, Pl. 112, fig. 19.

cf. *Erismodus? expansus* (Branson and Mehl). Andrews, 1967, p. 895, Pl. 114, figs. 16, 23.

Remarks. Elements assigned to the form genera *Erismodus*, *Microcoelodus* and *Ptiloconus* are morphologically variable, but several authors have noted that they commonly co-occur and intergrade morphologically. Andrews (1967) was the first to attempt to group elements under species of *Erismodus* and thus the name has priority. Sweet (1982) provided a review of the genus.

The specimens at hand most closely conform to *Erismodus typus* Branson and Mehl and they occur with elements ascribable to other form species of *Erismodus*

recognized by Andrews (1967). As noted by Bauer (1987) in his discussion of this genus, it is difficult to identify all elements of the apparatus of *E. typus* based on Andrews' (1967) and Ethington and Clark's (1982) illustrations. In the Rockcliffe collections there are clearly recognizable *a* elements that are not apparent in Andrew's (1967) material, although they may have been classified within the scope of his *E. asymmetricus*. The *b* and *c* elements are similar to elements described by Andrews (1967) as *E. typus* and *E. symmetricus*. The *e* elements recognized in the Rockcliffe collection are most similar to Andrews' (1967) illustration of *Erismodus gracilis* (Branson and Mehl) because they have a denticulate, anterior to anterolateral process and an adenticulate posterior extension. The *f* elements are most similar to forms identified by Andrews (1967) as *E. asymmetricus*. The *g* elements in the Rockcliffe collection are most similar to *Erismodus*? *expansus* as illustrated by Andrews (1967).

Andrews (1967) described the elements that he assigned to most of the form species of *Erismodus* as having rounded denticles. The Rockcliffe specimens, however, have pronounced edges on the cusp and most denticles. Sweet (1982) recognized the species *E. quadridactylus* (Stauffer) and noted that it had an apparatus similar to other species of the genus, except that the denticles were characteristically long, slender and marginally costate. None of the Rockcliffe elements is similar to elements of *E. quadridactylus* because they lack the delicate form, and denticles are few and generally robust, instead of discrete and slender. Bauer (1987) distinguished a new species *E. arbucklensis*, which he recognized because the elements are smaller than those of other described species and the denticles quite strongly compressed. The *a* elements in the Rockcliffe collection (see Pl. 1.4, fig. 2) are similar to those of *E. arbucklensis*, but the remainder of the elements are much more robust and less pronouncedly denticulate.

Thus the elements are most similar to those illustrated by Branson and Mehl (1933) and Andrews (1967), which can be grouped into an apparatus, the appropriate name for which is that of the type species, *E. typus*. However, there are some minor differences that preclude a firm identification. The Rockcliffe specimens have distinct cusp edges that are not described by Andrews (1967) and are not discernible in most of his illustrations. Furthermore the denticles on the Rockcliffe specimens, particularly those on the lateral processes of *b* and *c* elements and the anterolateral process of *e* and *g* elements, tend to be partially fused and even nodose in extreme cases (Pl. 1.4, fig. 3).

Species of *Erismodus* have very similar apparatuses distinguished mainly on the basis of size and degree of compression of denticles and cusp. The smaller elements are generally more compressed and bear more discrete denticles. These distinctions will probably cause some difficulty in the taxonomy of erismodans because, in large collections, a wide range of size and degree of denticle compression and discreteness can be observed. Erismodans, indeed, are hyaline forms, which are notorious for their degree of morphologic plasticity (Barnes et al., 1979).

Types. Figured specimens, GSC 90626-90631.

Material. *a* elements: 20; *b* elements: 36; *c* elements: 8; *e* elements: 19; *f* elements: 18; *g* elements: 5.

Genus *Oneotodus* Lindström, 1955

Type species. *Distacodus*? *simplex* Furnish, 1938.

Oneotodus? sp. cf. *O.*? *ovatus* (Stauffer, 1935)

Plate 1.4, figure 1

cf. *Oistodus ovatus* Stauffer, 1935, p. 147, Pl. 12, fig. 34.

cf. *Oneotodus*? *ovatus* (Stauffer). Bauer, 1987, Pl. 3, fig. 28 (includes synonymy to date).

Remarks. This form is similar in most respects to the element illustrated as *O.*? *ovatus* by Bauer (1987), except that the aboral margin is rounded and the aboral edge is constricted inward basally such that the basal opening is smaller in diameter than the lower part of the base. The virtual lack of a basal cavity is sufficient reason to question the generic assignment. Elements assigned to *Stereoconus* Branson and Mehl and *Evencodus* Moskalenko lack significant basal cavities. Species of *Stereoconus* are generally compressed with a flaring aboral margin and may possess ornamentation on the cusp. Species of *Evencodus* are characterized by downward extensions of the aboral margin and are also commonly ornamented, therefore it is difficult to assign the Rockcliffe specimens satisfactorily to an existing genus.

Types. Figured specimen, GSC 90625.

Material. 2 specimens.

Genus *Phragmodus* Branson and Mehl, 1933

Type species. *Phragmodus primus* Branson and Mehl.

Phragmodus flexuosus Moskalenko, 1973

Plate 1.3, figures 4, 5, 7-13

Phragmodus flexuosus Moskalenko, 1973, p. 73, 74, Pl. 11, figs. 4-6; Barnes, 1977, p. 103, Pl. 2, figs. 3, 4.

Phragmodus flexuosus Moskalenko morphotype A Bauer, 1987, p. 24, 25 Pl. 3, figs. 10, 14, 15, 18, 20, 24, Textfig. 8A (includes synonymy to date).

Remarks. In his review of this species, Bauer pointed out that there are two distinct groups of elements traditionally referred to this taxon. One group has a cyrtoniodiform e element and the other has a geniculate coniform *e* element. He noted that it was uncertain which group Moskalenko (1973) was dealing with when she erected the species, but Bauer (1987) adopted the pragmatic solution of regarding the apparatus with a cyrtoniodiform element as true *P. flexuosus*. He went on to recognize two morphotypes, one (morphotype A) which has readily distinguishable *f* and *g* elements and the other (morphotype B) which has undifferentiated P (*f* and *g*) elements. The Rockcliffe collection is clearly assignable to morphotype A.

Types. Hypotypes, GSC 90615-90623.

Material. *a-d* elements: 116; *e* elements: 47; *f* elements: 39; *g* elements: 25.

Genus *Plectodina* Stauffer, 1935

Type species. *Prioniodus aculeatus* Stauffer, 1930.

Plectodina? *ctenulata* (Youngquist and Cullison, 1946)

Plate 1.3, figures 1-3, 6

Ozarkodina ctenulata Youngquist and Cullison, 1946, p. 588, Pl. 89, fig. 3; Lee, 1975, p. 176, Pl. 2, fig. 10; Lee, 1977, p. 136, 137, Pl. 2, fig. 6, Pl. 3, fig. 5; Lee, 1980, Pl. 2, fig. 4.

Description. Only zygognathiform (*b*), trichonodelliform (*c*) and ozarkodiniform (*g*) elements have been identified with certainty. A cyrtoniodiform (*e*) element is also tentatively included in the apparatus. Zygognathiform *b* element is asymmetrical with lateral processes of unequal length. Denticles are anteroposteriorly compressed. Cusp is rounded anteriorly with sharp lateral and posterior costae. Trichonodelliform *c* element is similar to *b* element but is nearly symmetrical with lateral processes of subequal length, which are more strongly anteroposteriorly compressed. Posterior costa on cusp is produced posteriorly as a process that may be short, but is broken on all available specimens.

A cyrtoniodiform *e* element with a broad, laterally compressed cusp may also be a part of this apparatus. Cusp bears a weak inner carina, outer face is smoothly convex. Posterior process broken but may be short and appears virtually adenticulate, except for an indistinct oral convexity near posterior margin of main cusp.

Ozarkodiniform (*g*) elements are the best preserved and most abundant. Anterior process is high with up to six biconvex denticles that are fused for most of their length. Cups sharp-edged, posteriorly reclined and biconvex; it is significantly higher than denticles of anterior process. There is a gentle, narrow basal flare beneath the main cusp, which in some specimens is restricted to the aboral margin, whereas in others there is a narrow lateral carina on the base that is confluent with the cusp. Basal cavity is shallow. Posterior process shorter and lower than anterior process, and has up to four denticles that are more discrete than those on anterior process.

The *g* element is gently arched. White matter is present in denticles of all elements; in some it is cloudy and translucent, whereas in others it is more dense and relatively opaque.

Remarks. The *g* element of this species is characteristic of the apparatus. As only three or four of a presumed total of six elements have been found for this apparatus, the generic designation is questioned. Neither Youngquist and Cullison (1946) nor Lee (1975, 1977, 1980) have reported other elements associated with the form species *Ozarkodina ctenulata* and they are not fully represented in the Rockcliffe material. However, it seems likely that this form is ascribable to *Plectodina*.

Lee (1977) included *Ozarkodina joachimensis* Andrews in synonymy with *O. ctenulata*, but that species is quite distinct in having discrete, rounded denticles, although it is similar in the relationship of height of anterior and posterior processes.

The elements referred to *Bryantodina* sp. by Rexroad et al. (1982) and Bauer (1987) are superficially similar to this species, but possess more numerous and more slender denticles.

Types. Figured specimens, GSC 90611-90614.

Material. b elements: 8; *c* elements: 5; ?*e* elements: 2; *g* elements: 10.

Genus *Trigonodus* Nieper, 1969; emended Cooper, 1981

Type species. Oistodus larapintinensis (Crespin, 1943).

Trigonodus sp. cf. *T. sinuosus* (Mound, 1965)

Plate 1.4, figure 12

cf. *Scandodus sinuosus* Mound, 1965, p. 33, 34, Pl. 4, figs. 21, 22, 24, Textfig. 1J.

cf. *Acontiodus curvatus* Mound, 1965, p. 11, 12, Pl. 1, figs. 19-21, Textfig. 1D.

cf. *Distacodus symmetricus* Mound, 1965, p. 16, Pl. 2, figs. 1?, 2, 3?, Textfig. 1E.

Remarks. Cooper (1981) revived the genus *Trigonodus* and described the type species *T. larapintinensis* as a seximembrate multielement apparatus with a four-element S series (Sa, Sb, Sc, Sd), oistodontiform M elements and scandodontiform P elements. Elements ascribed to *Acontiodus curvatus*, *Scandodus sinuosus* and some of the elements ascribed to *Distacodus symmetricus* by Mound (1965) form a similar apparatus that can be interpreted differently. The putative apparatus of *T. sinuosus* comprises slender drepanodontiform (*a*, Sc) elements, asymmetrical scandodontiform (*b*, Sb) elements, acontiodontiform (*c*, Sa) elements, distacodiform (*d*, Sd) elements and broad drepanodontiform (*e*, M) elements. The latter are variably planar or bend to the inner side (scandodontiform) and it is possible that the *e* position is occupied by more than one element or alternatively that some can be interpreted as *f* or *g* (P) elements. This interpretation differs from that of Cooper (1981) for the genus but includes the same type of elements. Cooper's oistodontiform M element is only barely geniculate and very similar to the equivalent drepanodontiform element of *T. sinuosus*. Other element positions of Cooper's reconstruction can be reinterpreted as follows: drepanodontiform (Sd) element as *a* (Sc); scandodontiform (P) element as *b* (Sb); distacodontiform (Sa) element as *d* (Sd). Cooper (1981) does not illustrate an acontiodontiform element: his symmetrical element appears to be distacodontiform, but only one side is illustrated.

This re-evaluation of the reconstruction provided by Cooper (1981) results from the present author's recent studies of Ordovician simple cone apparatuses. It appears that many simple cone apparatuses follow an apparatus plan containing an intergradational symmetry series (*a* through *c* or *a* through *d* elements) with additional elements that can be interpreted as a single *e* (M) element or a series of subtly different elements of uncertain homology. This condition has been recognized in several Upper Ordovician simple cone taxa (see discussion of *Staufferella*, *Scabbardella* and *Walliserodus* in Nowlan et al. (1988).

The specimens from the Rockcliffe are few in number and are generally short and more robust than typical elements described by Mound (1965). Accordingly they are not considered unequivocally conspecific with *T. sinuosus*.

Types. Figured specimen, GSC 90636.

Material. a elements: 1; *b* elements: 6; *c* elements: 2; *d* elements: 1; *e* elements: 2.

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PLATE 1.1

All ostracodes are from sample Rc-6 (GSC loc. 102169)

Figures 1-6. *Sigmobolbina* sp.

1. Right lateral view of carapace, figured specimen, GSC 85985, x103.

2. Lateral view of right valve, figured specimen, GSC 85986, x99.

3. Lateral view of left valve, figured specimen, GSC 85987, x104.

4. Right lateral view of carapace, figured specimen, GSC 85988, x104.

5. Lateral view of left valve, figured specimen, GSC 85989, x125.

6. Right lateral view of carapace, figured specimen, GSC 85990, x152.

Figures 7, 8. *Lomatobolbina ottawaensis* Copeland sp. nov.

7. Lateral view of heteromorphic left valve, holotype, GSC 85991, x108.

8. Left lateral view of tecnomorphic carapace, paratype, GSC 95992, x109.

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PLATE 1.2

All ostracodes from sample Rc-6 (GSC loc. 102169)

Figures 1-4. *Eurychilina placida* Swain

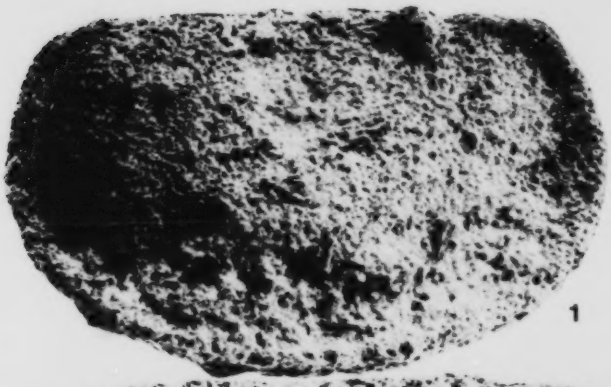
1. Lateral view of left valve, hypotypes, GSC 85993, x88.
2. Lateral view of left valve, hypotye, GSC 85994, x136.
3. Lateral view of left valve, hypotype, GSC 85995, x196.
4. Interior view of left valve, hypotype, GSC 85996, x103.

Figures 5, 6. *Pseudulrichia*? sp.

5. Lateral view of left valve, figured specimen, GSC 85997, x77.
6. Lateral view of left valve, figured specimen, GSC 85998, x59.

Figures 7, 8. *Conchoprimitia*? sp.

7. Lateral view of left valve, figured specimen, GSC 85999, x125.
8. Interior view of left valve, figured specimen, GSC 86000, x105.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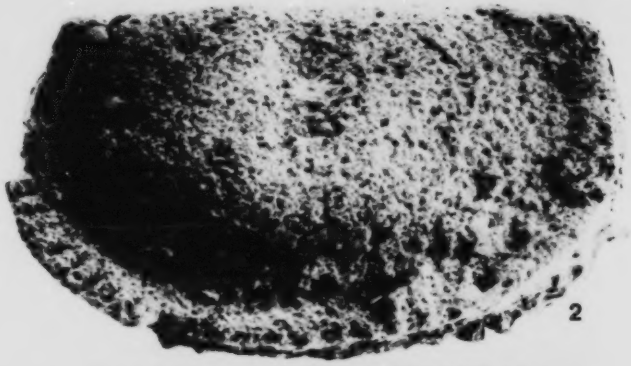
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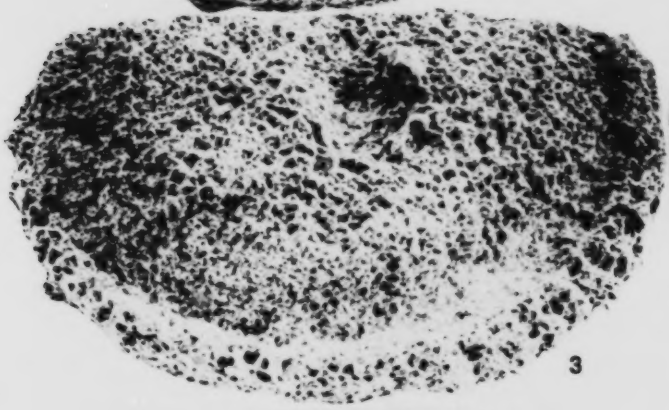
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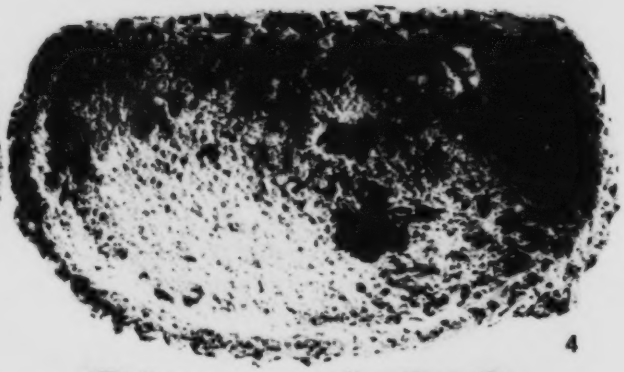
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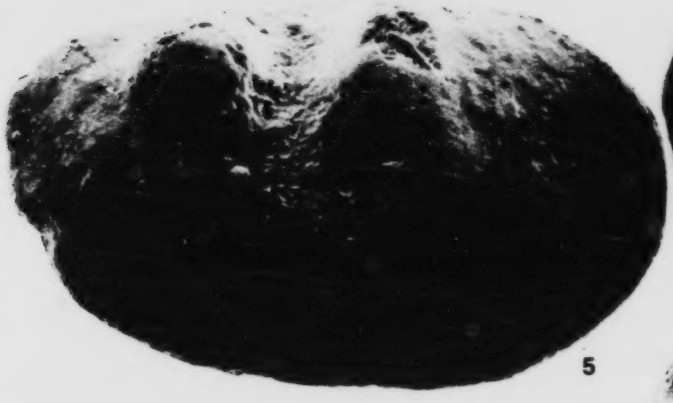
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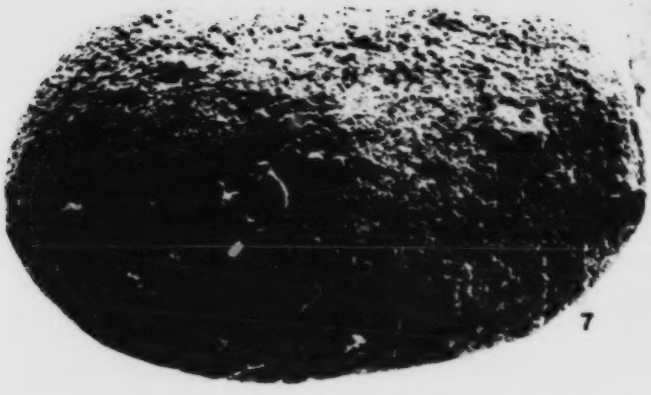
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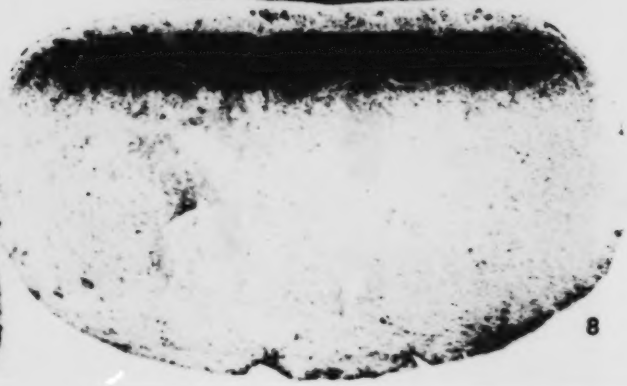
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PLATE 1.3

All conodonts from sample Rc-6 (GSC loc. 102169)

Figures 1-3, 6. *Plectodina*? *ctenulata* (Youngquist and Cullison)

1. Posterior view, *b* element, figured specimen, GSC 90611, x96.

2. Posterior view, *c* element, figured specimen, GSC 90612, x96.

3. Lateral view, *g* element, figured specimen, GSC 90613, x70.

6. Inner lateral view of fragmentary *e*(?) element, figured specimen, GSC 90614, x96.

Figures 4, 5, 7-13. *Phragmodus flexuosus* Moskalenko

4. Inner lateral view, *b* element, hypotype, GSC 90615, x90.

5. Outer lateral view, *d* element, hypotype, GSC 90616, x60.

7. Inner lateral view, *f* element, hypotype, GSC 90617, x50.

8. Outer lateral view, *f* element, hypotype, GSC 90618, x60.

9. Outer lateral view *a* element, hypotype, GSC 90619, x67.

10. Outer lateral view, *g* element, hypotype, GSC 90620, x60.

11. Inner lateral view, *e* element with long posterior process and short anterobasal extension, hypotype, GSC 90621, x60.

12. Inner lateral view, *e* element with short posterior process and long anterobasal extension, hypotype, GSC 90622, x60.

13. Oral view, *g* element, hypotype, GSC 90623, x60.

Figure 14. *Trucherognathus distorta* Branson and Mehl.

Lateral view, hypotype, GSC 90624, x72.

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PLATE 1.4

All conodonts from sample Rc-6 (GSC loc. 102169)

Figure 1. *Oneotodus*? sp. cf. *O.? ovatus* (Stauffer)

Lateral view, figured specimen, GSC 90625, x117.

Figures 2-4, 6, 7, 9. *Erismodus* sp. cf. *E. typus* Branson and Mehl

2. Inner lateral view, *a* element, figured specimen, GSC 90626, x105.

3. Posterolateral view, *b* element, figured specimen, GSC 90627, x87.

4. Inner lateral view, *b* element, figured specimen, GSC 90628, x67.

6. Inner lateral view, *e* element, figured specimen, GSC 90629, x57.

7. Posterior view, *c* element, figured specimen, GSC 90630, x74.

9. Outer lateral view, *f/g* element, figured specimen, GSC 90631, x48.

Figure 5. *Polycaulodus gracilis* Youngquist and Cullison s.f.

Lateral view, hypotype, GSC 90632, x35.

Figures 8, 10. *Coleodus pectiniformis* Youngquist and Cullison

8. Lateral view, hypotype, GSC 90633, x41.

10. Lateral view, (?)juvenile element with discrete denticles, hypotype, GSC 90634, x76.

Figure 11. *Polycaulodus bidentatus* Branson and Mehl s.f.

Posterior view, hypotype, GSC 90635, x90.

Figure 12. *Trigonodus* sp. cf. *T. sinuosus* (Mound)

Lateral view *c* element, hypotype, GSC 90636, x60.

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RHYNCHONELLID BRACHIOPODS FROM THE UPPER ORDOVICIAN-LOWER SILURIAN BEAVERFOOT AND NONDA FORMATIONS OF THE ROCKY MOUNTAINS, BRITISH COLUMBIA

J. Jin[1], W.G.E. Caldwell[2], and B.S. Norford[3]

Jin, J., Caldwell, W.G.E., and Norford, B.S., Rhynchonellid brachiopods from the Upper Ordovician-Lower Silurian Beaverfoot and Nonda formations of the Rocky Mountains, British Columbia. In Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 396, p. 21-59, 1989.

Abstract

The rhynchonellid brachiopods of the Upper Ordovician-Lower Silurian Beaverfoot and Lower Silurian Nonda formations in the Canadian Rocky Mountains are referred to three families, eight genera, and seventeen species, two of which, *Lepidocycloides rudicostatus* and *Hercotrema humiliseptatum*, are new.

The Beaverfoot Formation contains two distinct rhynchonellid faunas. The Ashgill *Hypsiptycha-Lepidocyclus* fauna of the lower Beaverfoot Formation has a high diversity, with eight species belonging to five genera: *Hypsiptycha occidens, H. neenah, Lepidocyclus erectus, Hiscobeccus kananaskia, H. windermeris, Rostricellula pisina, Gnamptorhynchos inversum*, and *Lepidocycloides rudicostatus*. The generic composition indicates a close affinity between the Rocky Mountains fauna and the coeval faunas of other regions of the North American craton. *Lepidocycloides* is an obvious exception; its affinity is with the Upper Ordovician rhynchonellid fauna of the Siberian Platform. The Llandovery *Stegerhynchus* fauna of the upper Beaverfoot Formation is of relatively low diversity. It contains only four species belonging to three genera; *Stegerhynchus praecursor, S. peneborealis, Hercotrema winiskensis*, and *Gnamptorhynchos* sp. In the *Stegerhynchus* fauna of the Nonda Formation, only two of the genera found in the upper Beaverfoot Formation are present, and they are represented by distinct species: *Stegerhyncus borealis, S. concinna, Hercotrema humiliseptatum*, and *H. winiskensis*. The presence of *S. borealis, S. praecursor*, and *H. winiskensis* indicates that the rhynchonellid faunas of the upper Beaverfoot and Nonda formations are closely related to the coeval or later faunas of the Canadian Arctic, Hudson Bay Lowlands, Michigan Basin, and Anticosti Island.

The Ashgill and Llandovery ages of the *Hypsiptycha-Lepidocyclus* fauna and the *Stegerhynchus* fauna, respectively, are confirmed by other fossils (atrypid and pentamerid brachiopods, conodonts, and rugose corals) present in the Beaverfoot and Nonda formations. Distribution of the rhynchonellid faunas in the Beaverfoot Formation constrains the position of the Ordovician-Silurian Boundary.

Résumé

Les brachiopodes rhynchonellidés des formations de Beaverfoot de l'Ordovicien supérieur et Silurien inférieur et de Nonda du Silurien inférieur dans les montagnes Rocheuses canadiennes font partie de trois familles, huit genres et 17 espèces, dont deux espèces, *Lepidocycloides rudiocostatus* et *Hercotrema humiliseptatum*, sont nouvelles.

La formation de Beaverfoot contient deux faunes distinctes de rhynchonellidés. La faune *Hypsiptycha-Lepidocyclus* de l'Ashgillien de la partie inférieure de la formation de Beaverfoot est très diversifiée, comptant huit espèces appartenant à six genres : *Hypsiptycha occidens, H. neenah, Lepidocyclus erectus, Hiscobeccus kananaskia, H. windermeris, Rostricellula pisina, Gnamptorhynchos inversum* et *Lepidocycloides rudicostatus*. La composition du genre indique une étroite affinité entre la faune des montagnes Rocheuses et les faunes contemporaines d'autres régions du craton de l'Amérique du Nord. *Lepidocycloides* est une exception évidente; il présente une affinité avec la faune de rhynchonellidés de l'Ordovicien supérieur de la plate-forme sibérienne. La faune *Stegerhynchus* du Llandovérien de la partie supérieure de la formation de Beaverfoot est relativement peu variée. Elle ne contient que quatre espèces réparties en trois genres : *Stegerhynchus praecursor, S. peneborealis, Hercotrema winiskensis* et *Gnamptorhynchos* sp. Dans la faune *Stegerhynchus* de la formation de Nonda, on ne retrouve que deux des genres présents dans la partie supérieure de la formation de Beaverfoot, lesquels sont représentés par deux espèces distinctes : *Stegerhynchus borealis, S. concinna, Hercotrema humiliseptatum* et *H. winiskensis*. La présence de *S. borealis, S. praecursor* et *H. winiskensis* indique que les faunes de rhynchonellidés de la partie supérieure des formations de Beaverfoot et de Nonda sont étroitement liées aux faunes contemporaines ou ultérieures relevées dans l'Arctique canadien, les basses terres de la baie d'Hudson, le bassin de Michigan et l'île d'Anticosti.

Les faunes *Hypsiptycha-Lepidocyclus* et *Stegerhynchus* dateraient de l'Ashgillien et du Llandovérien respectivement, tel que confirmé par d'autres fossiles (brachiopodes atrypidés et pentaméridés, conodontes et coraux rugueux) présents dans les formations de Beaverfoot et de Nonda. La répartition des faunes de rhynchonellidés dans la formation de Beaverfoot restreint la position de la limite ordovicienne et silurienne.

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INTRODUCTION

Rhynchonellid brachiopods are a prominent component of the Ordovician and Silurian faunas of the carbonate platform fringing the North American craton in the Canadian Rocky Mountains. In the south, rhynchonellids are abundant and diverse in the Upper Ordovician part of the Beaverfoot Formation, but they are less common and less varied in the Lower Silurian part, as well as in the Lower Silurian Nonda Formation in the north (Fig. 2.1a). Biostratigraphic correlation using other groups of fossils present in the two formations allows independent dating of the rhynchonellid faunas. The dating is most precise in the lower (Ashgill) and upper (middle and upper Llandovery) parts of the stratigraphic sequence. All groups of fossils are rare near the Ordovician-Silurian boundary.

The only previous taxonomic study of rhynchonellids from the region was that by Wilson (1926), within her general study of Middle Ordovician to Lower Silurian collections from the Skoki and Beaverfoot formations. She established four new species and assigned them to *Rhynchotrema*. *Rhynchotrema kananaskia* (now assigned to *Hiscobeccus*) and *R. occidens* (now *Hypsiptycha*) are common in many stratigraphic sections of the lower Beaverfoot Formation (Evans, 1933; Leech, 1954; Norford, 1969). *Rhynchotrema windermeris* (now *Hiscobeccus*) and *R. pisina* (now *Rostricellula*) are rare in the same sections. Rhynchonellids from the Silurian part of the Beaverfoot Formation have not been described previously, but their presence has been noted (Henderson, 1954; Norford, 1969). Similarly, Norford et al. (1967) reported the presence of "*Camarotoechia*" (= *Hercotrema* Jin, 1989) from the Lower Silurian Nonda Formation in northern British Columbia.

The present study is based on about 320 specimens from 25 localities (Fig. 2.1a, 1b). Most of the collections were made by B.S. Norford from 1959 to 1965. Older collections (including many studied by Wilson, 1926) were made by L.D. Burling, in 1915, J.R. Marshall, and E.M. Kindle in 1923, J.F. Walker in 1924, C.S. Evans in 1925, and G.B. Leech between 1953 and 1962. In 1987, B.S. Norford and J. Jin supplemented the available specimens by collecting rhynchonellids from the Pedley Pass (standard section of the Beaverfoot Formation), Alces Lake, and other sections.

Most rhynchonellids from the Beaverfoot and Nonda formations are silicified in a dolomitic matrix. The shells commonly can be separated from the matrix by acid-etching, and internal structures can be examined in the valves of disarticulated specimens. A few collections contain entire calcareous shells, which are ideal for serial sectioning. Some collections are difficult to study, however, because the shells and their internal matrices are silicified and recrystallized, and both external and internal structures are obscured.

STRATIGRAPHIC FRAMEWORK

In the southern Rocky Mountains, the Upper Ordovician-Lower Silurian Beaverfoot Formation is composed of up to 600 m of carbonate rocks. The original sediments were deposited in shallow, tropical waters on the western part of the Bow Platform (Cecile and Norford, in press). Part of that platform is indicated by the Beaverfoot outcrop belt, which extends from near Fernie in southeastern British Columbia almost to the Peace River in northern British Columbia (Fig. 2.1a). Other components of the coeval carbonate complex, such as the west-facing carbonate front

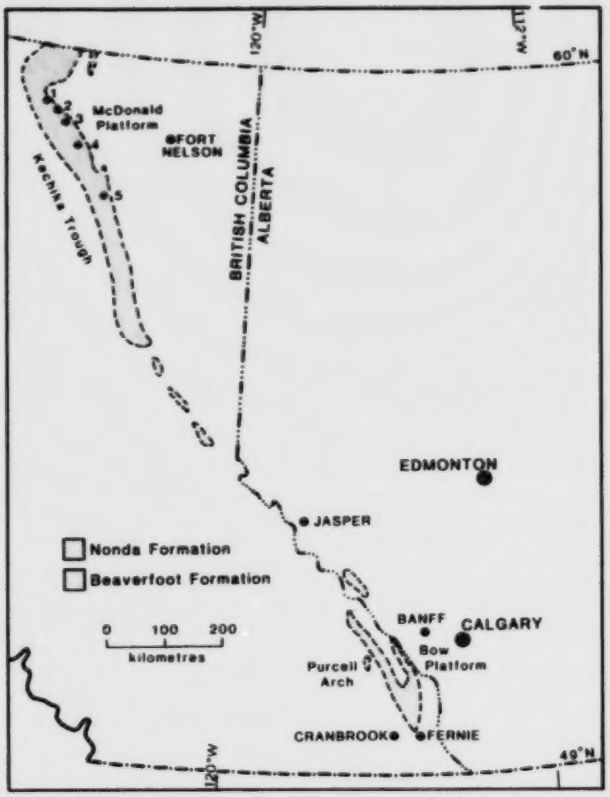

Figure 2.1a. *Distribution of the Beaverfoot and Nonda formations in the Rocky Mountains. Numbered dots indicate the rhynchonellid localities cited in the text: 1. Lapie Lake; 2. Mile 474, Alaska Highway; 3. Hoole Creek; 4. Toad River Bridge (type locality of the Nonda Formation); 5. Gathto Creek.*

and the transition into slope and basin siliciclastic deposits, are unknown, although remnants in the northern Rocky Mountains imply their development. Removal of the facies components from the south may be attributed to episodes of early Paleozoic erosion, now represented by unconformities that truncate westward to progressively lower stratigraphic levels. The Beaverfoot Formation is known to extend westward to the Purcell Arch, where its Upper Ordovician solitary coral faunas lack any taxa characteristic of continental-margin environments (Buttler et al., 1988, p. 57).

The unconformity below the Devonian rocks is an important regional structure. The thickest developments (up to 600 m) of the Beaverfoot Formation preserved beneath this unconformity are at Pedley Pass and in the Alces Lake – Akutlak Creek – Top of the World region. The lower 200 m of the Beaverfoot Formation are moderately fossiliferous and of Late Ordovician (Ashgill) age. The upper 200 m are similarly fossiliferous, of Early Silurian (Llandovery) age, and overlain by the Tegart Formation, which has the *Monograptus spiralis* Zone at its base. The intervening 200 m are poorly dated, but the earliest known Silurian rocks occur about 200 m above the formation base.

In the northern Rocky Mountains, the Lower Silurian Nonda Formation consists of up to 612 m of carbonate rocks, the original sediments of which were deposited in the

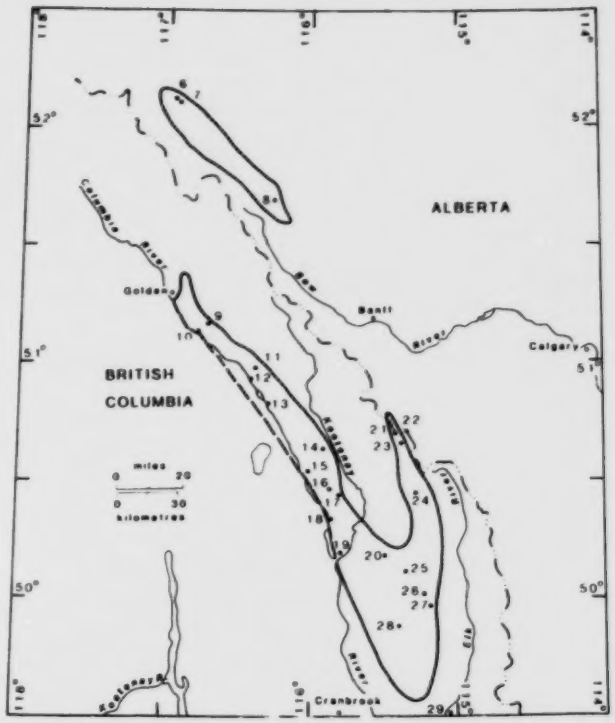

Figure 2.1b. *Additional rhynchonellid localities cited in the text: 6. Cirrus Mountain; 7. Mt. Coleman; 8. Pipestone River; 9. Carbonate Creek (type locality of the Beaverfoot Formation); 10. McMurdo; 11. Hatch Creek; 12. Harrogate; 13. Brisco; 14. Mt. Sinclair; 15. Stoddart Creek; 16. Windermere Creek; 17. Pedley Pass (standard section of the Beaverfoot Formation); 18. Fairmont; 19. Mt. Sabine; 20. Moscow Creek; 21. Palliser Pass; 22. Mt. Sir Douglas, 23. Tipperrary Lake; 24. Russell Peak; 25. Akutlak Creek; 26. Mt. Harrison; 27. Ridge between Bull River and Quinn Creek; 28. Top of the World.*

shallow, tropical waters of the McDonald Platform (Norford et al., 1967; Cecile and Norford, in press). A minimal extent for the platform is given by the long, narrow Nonda outcrop belt, which ranges from south of Peace River in British Columbia northward into the Yukon Territory (Fig. 2.1a).

Eastward, unconformities cut out the Nonda down to Cambrian and lower levels. Westward, the Nonda carbonate rocks undergo facies changes through reef carbonates of the west-facing carbonate front into siliciclastic basinal rocks of the Road River Group (Norford et al., 1967; Cecile and Norford, 1979). Fluctuating conditions may have influenced deposition on the McDonald Platform: fossiliferous dolomites with abundant corals, which dominate the Nonda succession, are interbedded with finer grained dolomites, seemingly barren of fossils, which may denote episodes of more prevalent saline conditions.

Several informal biostratigraphic zones were recognized in the Nonda Formation by Norford et al. (1967; and present report, Fig. 2.2). All of these are now considered to be of Middle to Late Llandovery age, with the youngest zone locally overlain by the uppermost Llandovery *Monograptus spiralis* Zone.

RHYNCHONELLID BIOSTRATIGRAPHY

Beaverfoot Formation

The rhynchonellids collected from measured sections and isolated outcrops of the Beaverfoot Formation in the southern Rocky Mountains fall into two distinct faunas: the *Hypsiptycha-Lepidocyclus* fauna and the *Stegerhynchus* fauna. The species composing the faunas are similar to those found in other North American basins, especially the Anticosti and Illinois basins (Wang, 1949; Howe, 1966; Alberstadt, 1973; Amsden, 1983; Jin, 1989), where the faunas are dated as Late Ordovician (Ashgill) and Early Silurian (Llandovery), respectively. Other groups of fossils (atrypid and pentamerid brachiopods, conodonts, and rugose corals) present in the Beaverfoot Formation reaffirm these respective ages for the rhynchonellid faunas in the southern Rocky Mountains. The rhynchonellid faunas, in turn, help to constrain the placement of the Ordovician-Silurian boundary.

The Ashgillian *Hypsiptycha-Lepidocyclus* fauna occurs mainly in the lower 80 m of the Beaverfoot Formation, within the *Bighornia-Thaerodonta* Zone of Norford (1962a, 1969) and of Buttler et al. (1988), which is about Richmondian in age in terms of the North American stages. The *Hypsiptycha-Lepidocyclus* fauna contains the following rhynchonellid species:

Hypsiptycha occidens (Wilson, 1926)
Hypsiptycha neenah (Whitfield, 1882)
Lepidocyclus erectus Wang, 1949
Hiscobeccus kananaskia (Wilson, 1926)
Hiscobeccus windermeris (Wilson, 1926)
Lepidocycloides rudicostatus n. sp.
Gnamptorhynchos inversum Jin, 1989
Rostricellula pisina (Wilson, 1926)

The fauna also may contain *Rhynchotrema* sp.

Hypsiptycha occidens is very similar to, and probably of the same age as, the Ashgill *Hypsiptycha janea* (Billings, 1862) from Anticosti Island. *Lepidocyclus erectus*, *Hiscobeccus kananaskia*, and *H. windermeris* can be compared to their counterparts from the Upper Ordovician rocks of Anticosti Island, American midcontinental basins, and the northeastern Williston basin (Jin, 1989; Wang, 1949; Alberstadt, 1973). *Lepidocycloides* was first recognized in the Upper Ordovician rocks of Siberia (Nikiforova in Nikiforova and Andreeva, 1961), and its appearance in the Beaverfoot Formation provides the first record of the genus in North America.

Disappearance of the *Hypsiptycha-Lepidocyclus* fauna in the lower Beaverfoot Formation presumably corresponds to the disappearance of this fauna in very late Ordovician rocks of other North American basins (Figs. 2.3, 2.4; Jin, 1989).

The Llandovery *Stegerhynchus* fauna of the upper Beaverfoot Formation contains the following four species:

Stegerhynchus praecursor Foerste, 1909
Stegerhynchus peneborealis (Twenhofel, 1928)
Gnamptorhynchos sp.
Hercotrema winiskensis (Whiteaves, 1906)

Stegerhynchus praecursor denotes the *Stegerhynchus* assemblage at Pedley Pass, occurring 385-388 m above the base of the Beaverfoot Formation. The beds containing the rhynchonellids lie within the *Eostropheodonta* Zone of Norford (1969) but well above the late Early to Middle Llandovery occurrences of the pentamerid brachiopods *Nondia* and ?*Virgiana* (GSC locs. 47404 and C-164509;

Norford, 1969, p. 72; Buttler et al., 1988, p. 50) in that zone. About 25 m below the occurrence of *S. praecursor*, a conodont faunule has been recovered (GSC loc. 45572), which is probably equivalent to the Middle Llandovery *Kentuckyensis* Zone, and about 70 m above the *S. praecursor* beds, within the basal *Pentamerus* Zone of Norford (1969), another conodont faunule is probably equivalent to the upper *Staurognathoides* Zone of Late Llandovery age (T.T. Uyeno, pers. comm., 1987). Thus, at Pedley Pass, the age of the *S. praecursor* beds is most probably Middle Llandovery, but could be as young as Late Llandovery. *Stegerhynchus praecursor* also occurs in the upper Beaverfoot Formation (from 250 m above the base) in the Hatch Creek section (Fig. 2.4), at Mount Sinclair, and near Moscow Creek. *Stegerhynchus peneborealis* is represented by only one specimen in an isolated outcrop of the Beaverfoot Formation, near Mount Harrison. Both *S. praecursor* and *S. peneborealis* are common rhynchonellids in the Middle and Upper Landovery rocks (Merrimack and Jupiter formations) of Anticosti Island, and *S. praecursor* is also present in the Clinton Group of Tennessee, which is of similar age (Berry and Boucot, 1970).

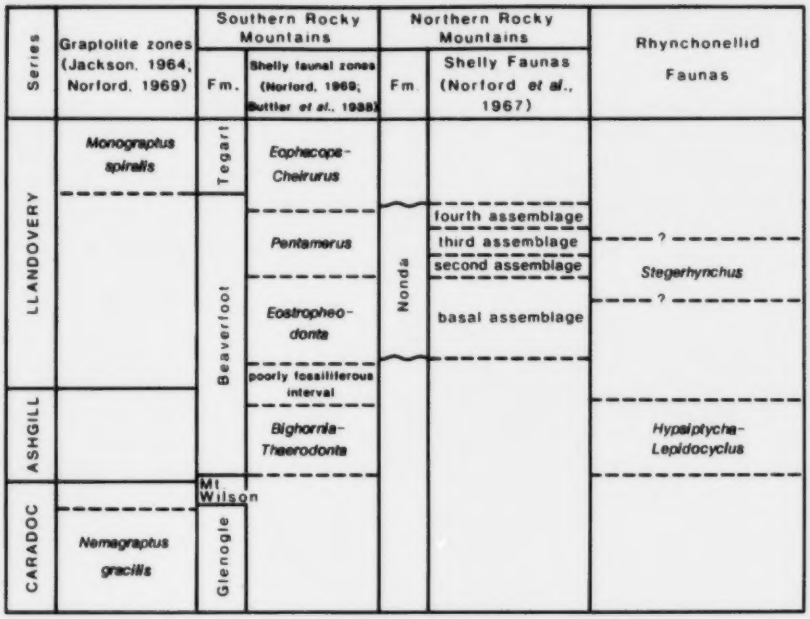

Figure 2.2. *Correlation of the rhynchonellid brachiopod faunas with the shelly faunal zones of Norford (1969). The* ***Hypsiptycha-Lepidocyclus*** *fauna in the Beaverfoot Formation contains other typical Ashgillian rhynchonellid genera, such as* ***Rostricellula, Hiscobeccus*** *and* ***Lepidocycloides.***

Nonda Formation

Four faunal assemblages have been discriminated within the Nonda Formation (Norford et al., 1967, p. 512-514). The uppermost can be correlated with the coralline member of the Sandpile Group (Norford, 1962a, 1962b), and at one location it underlies the Late Llandovery *Monograptus spiralis* Zone. *Nondia* and *Virgiana* were described later from the lowest faunal assemblage (Boucot and Chiang, 1974), and their age considered to be late Early to Middle Llandovery. No conodont studies have yet been carried out on the Nonda Formation.

The present study reveals four rhynchonellid species in the Nonda Formation:

Stegerhynchus borealis (von Buch, 1834)
Stegerhynchus concinna (Savage, 1913)
Hercotrema humiliseptatum n. sp.
Hercotrema winiskensis (Whiteaves, 1906)

All four species are present within the second faunal assemblage of the Nonda Formation, and *S. borealis* ranges up into the third assemblage. The second assemblage includes the brachiopods *Pentamerus* and *Alispira*, and the corals *Cystihalisites*, *Multisolenia* and *Columnaria columbia* Norford; it is Late Llandovery in age but significantly older than the *M. spiralis* Zone.

The type specimens of *Stegerhynchus borealis* from Gotland are Wenlock in age. On Anticosti Island, the species occurs in the Late Llandovery Jupiter Formation (Jin, 1989), and in the Arctic Islands in the Ludlow Read Bay Formation (Jones, 1981). The trigonirhynchiid *Hercotrema*, previously listed as "*Camarotoechia*" by Norford et al. (1967), has a long range. In Anticosti Island, *Hercotrema bulbicostatum* Jin,

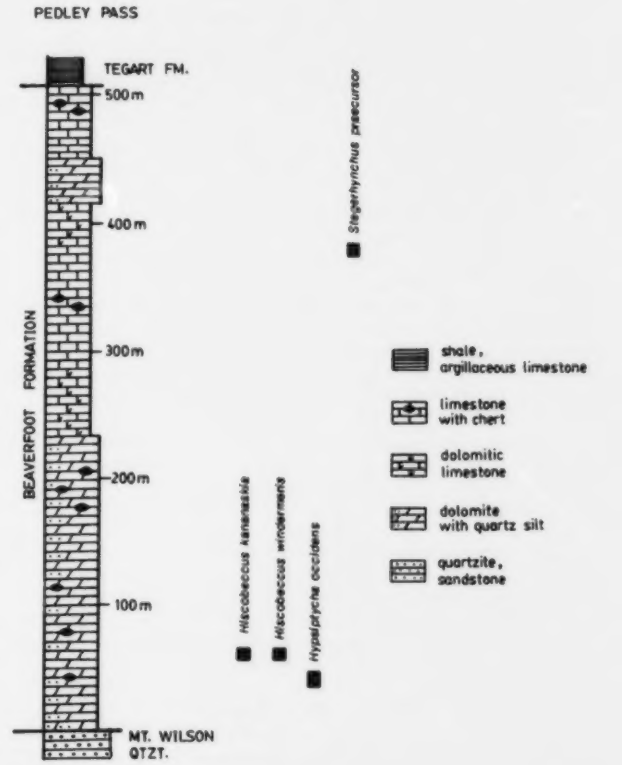

Figure 2.3. *Occurrence of rhynchonellid species in the Pedley Pass section of the Beaverfoot Formation.*

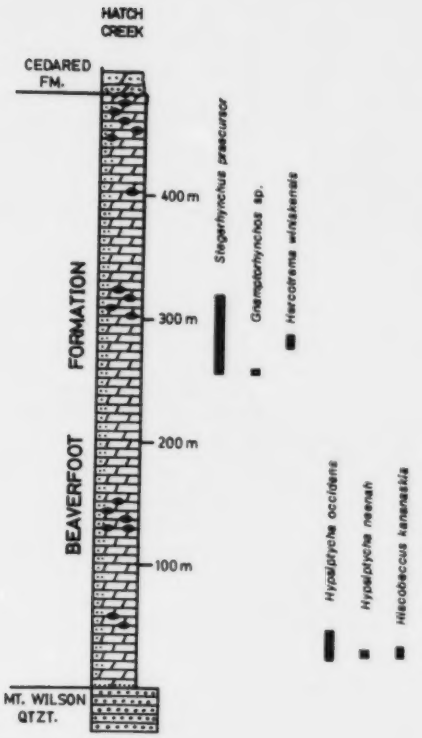

Figure 2.4. *Occurrence of rhynchonellid species in the Hatch Creek section (section at Harrogate of Evans, 1933) of the Beaverfoot Formation.*

1989, is Late Llandovery in age, and Bohemian species of *Hercotrema* (reported as *Stegerhynchus* by Havlicek, 1961) range in age from Early Silurian (Wenlock) to Early Devonian.

Stegerhynchus and *Hercotrema* in the Nonda Formation denote relatively early occurrences of these genera in British Columbia, similar to the occurrences in Anticosti Island. In contrast, the two genera have been reported only in Wenlock to Pridoli horizons in the Arctic Islands, Gotland, Estonia, and Bohemia (Jones, 1981; Bassett and Cocks, 1974; Rubel and Rozman, 1977; Havliček, 1961).

SYSTEMATIC PALEONTOLOGY

All specimens are deposited in the Type Collection of the Geological Survey of Canada, Ottawa.

Definitions of external and internal morphological features (including relative shell size) used in the following descriptions can be found in Jin (1989).

Phylum BRACHIOPODA Dumeril, 1806

Order RHYNCHONELLIDA Kuhn, 1949

Superfamily RHYNCHONELLACEA Grey, 1848

Family RHYNCHOTREMATIDAE Schuchert, 1913

Diagnosis. Costae generally simple, angular to subrounded, beginning at apex of umbones, crossed by concentric fine growth lines to imbricate lamellae. Pedicle sulcus and brachial fold present. Delthyrium open to completely covered by deltidial plates. Dental plates present, rarely fused to shell wall. Septalium developed to varying degrees, with or without well formed septalial plates. Hinge plates usually large, thick. Cardinal process septiform. Crura commonly radulifer.

Genera assigned.

Rhynchotrema Hall, 1860
Stegerhynchus Foerste, 1909
(= *Stegorhynchella* Rzhonsnitskaya, 1959)
Ferganella Nikiforova, 1937
Lepidocyclus Wang, 1949
Hypsiptycha Wang, 1949
Pleurocornu Havliček, 1960
Hiscobeccus Amsden, 1983

Age. Middle Ordovician – Late Devonian.

Genus *Rhynchotrema* Hall, 1860

Type species. *Atrypa increbescens* Hall, 1847, p. 146, Pl. 33, figs. 13a-d (*non* 13 e-y). Trenton Limestone. Middle Ordovician (upper Caradoc). New York.

Diagnosis. (Emended after Schmidt and McLaren, 1965.) Pedicle umbo uniformly convex. Delthyrium open or with rudimentary deltidial plates. Pedicle sulcus and brachial fold beginning anterior of umbo. Costae simple, subangular to subrounded. Dental plates commonly developed. Muscle field flabellate, generally striated. Septalium formed by well developed septalial plates. Cardinal process septiform. Crura commonly radulifer.

Remarks. Howe (1965) compared Wang's (1949) and Cooper's (1956) definitions of *Rhynchotrema* and noted six contradictory character descriptions, such as presence or absence of deltidial plates, cardinal process, and dental plates. The delthyrium in *Rhynchotrema* is commonly covered by marginal deltidial plates. In some specimens, however, the plates may be so rudimentary that the delthyrium appears open. Wang (1949) stated that the presence of a cardinal process in the genus was questionable. This was probably due to his observations being based mainly on disarticulated valves in which the delicate blade-like process was broken. Serial sectioning of well preserved shells indicates that a cardinal process is consistently present in *Rhynchotrema*.

Rhynchotrema differs from *Lepidocyclus* and *Hypsiptycha* in its lack of prominent growth lamellae and in its more rudimentary deltidial plates. Internally *Rhynchotrema* has well delimited septalial plates, whereas *Lepidocyclus* has short septalial plates, and *Hypsiptycha* lacks such plates. *Rhynchotrema* resembles *Hiscobeccus* in lacking deltidial plates, but *Hiscobeccus* has strong growth lamellae.

Species assigned.

Atrypa increbescens Hall, 1847
(= *Rhynchotrema wisconsinense* Fenton and Fenton, 1924
= *Rhynchotrema inaequivalvis* Winchell and Schuchert, 1895
Synonymy discussed in Weiss, 1955, Cooper, 1956, and Alberstadt, 1973)
Atrypa dentata Hall, 1847
Rhynchonella fringilla Billings, 1862

Rhynchonella nutrix Billings, 1866
Rhynchotrema kentuckiense Fenton and Fenton, 1924
(= *R. inaequivalvis* Winchell and Schuchert, 1895, in part. See synonymy in Cooper, 1956)
Rhynchotrema plicata Cooper and Kindle, 1936
Rhynchotrema iowense Wang, 1949
Rhynchotrema otarica Rukavishnikova, 1956
Rhynchotrema costulata Misius, 1986
Rhynchotrema parviseptatum Jin, 1989

Species questionably assigned.

Rhynchotrema borealis Nasedkina, 1973
Rhynchotrema uralica Nasedkina, 1973
Rhynchotrema minuta Misius, 1986

The Middle Ordovician *R. borealis* and Upper Ordovician *R. uralica* from the Ural Mountains have medium-sized shells with septiform cardinal processes. Nasedkina (1973) did not illustrate the internal structures of these two species and distinguished *R. borealis* from *R. increbescens* by its larger shell, more pronounced fold and sulcus, and more convex pedicle umbo. Misius (1986) described *R. minuta* from the Middle Ordovician rocks of Kirgiz, U.S.S.R., but did not comment on the presence or absence of a cardinal process in the species.

Species excluded.

Rhynchotrema yaoxianensis Fu, 1982
R. yaoxianensis from the Upper Ordovician rocks of Northern China lacks a median septum, a septalium, and a cardinal process.

Age. Middle Ordovician – Early Silurian.

Rhynchotrema sp.

Plate 2.1, figures 1-4

Description. Shell medium-sized, 12.0 mm long, 12.6 mm wide, 5.5 mm thick. Pedicle umbo weakly convex, noncarinate, with beak broken. Sulcus very shallow, developed anteriorly, occupied by three simple, subrounded costae. Brachial umbo nearly flat, marked by median furrow. Fold low, rising slightly above shell contour in anterior half of shell, bearing four simple costae. Each shell flank with seven to eight simple, subrounded costae.

Remarks. Only one, somewhat flattened, specimen was collected from the Beaverfoot Formation. The shell is assigned to *Rhynchotrema* on the basis of its external features.

Collections. Beaverfoot Formation. GSC loc. 8060 (one shell), collected by C.S. Evans on ridge between first and second creeks north of Brisco; the exact stratigraphic position of the specimen is uncertain because of faulting.

Genus *Hypsiptycha* Wang, 1949

Type species. Hypsiptycha hybrida Wang, 1949, p. 17, Pl. 10B, figs. 1-9. Brainard Member, Maquoketa Formation. Upper Ordovician, Iowa.

Diagnosis. Shell small to medium-sized, unequally biconvex with deeper brachial valve. Pedicle umbo high, narrow, with suberect or erect beak. Delthyrium covered by conjunct deltidial plates. Costae strong, simple, crossed by growth lamellae. Pedicle sulcus and brachial fold well developed. Dental plates present. Septalium small, with poorly formed septalial plates. Cardinal process septiform. Crura radulifer.

Species assigned.

Rhynchonella anticostiensis Billings, 1862
Rhynchonella janea Billings, 1866
Rhynchonella neenah Whitfield, 1882
Rhynchotrema occidens Wilson, 1926
Hypsiptycha hybrida Wang, 1949

Species questionably assigned.

Rhynchonella argenturbicum White, 1377 (see Howe, 1967)

In his study of *Hypsiptycha argenturbicum* (White), Howe (1967) found few significant morphological differences between *H. anticostiensis*, *H. argenturbicum*, and *H. hybrida*, except for differences in shell size and dimensions (length/width and thickness/width ratios). *Hypsiptycha argenturbicum* shows considerable overlap with *H. anticostiensis* in shell dimensions. The type specimens of *H. anticostiensis* range from 12.5 to 17.5 mm in length (with an average of 14.4 mm), and the specimens used by Howe (1967) for *H. argenturbicum* range from 4 to 15 mm in length (average about 9 mm). The thickened cardinal process observed in serial sections of *H. anticostiensis* exists also in a silicified specimen of *H. argenturbicum* (Howe, 1967, Pl. 105, fig. 6).

Age. Late Ordovician (Ashgill).

Hypsiptycha occidens (Wilson, 1926)

Plate 2.1, figures 5-26; Plate 2.2, figures 1-10; Plate 2.9, figures 1-8; Figures 2.5, 2.6

1926 *Rhynchotrema increbescens* var. *occidens* Wilson, p. 21, Pl. 4, figs. 6-10.
1926 *Rhynchotrema pisina* Wilson, p. 22, Pl. 4, fig. 13 (*non* figs. 11, 12).
1969 *Rhynchotrema increbescens occidens* Wilson; Norford, p. 38 (no illustration, but his collections have been examined).

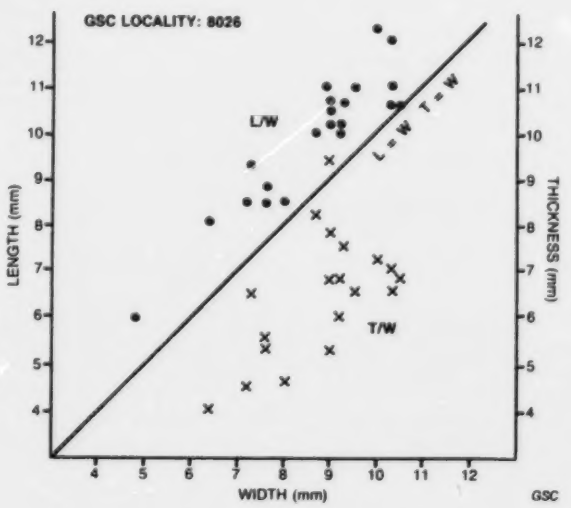

Figure 2.5. *Shell dimensions of* ***Hypsiptycha occidens*** *(Wilson, 1926). The sample is from the lower Beaverfoot Formation, near Brisco (GSC loc. 8026). The species shows a wide range of variation in shell convexity (T/W) in relatively large specimens.*

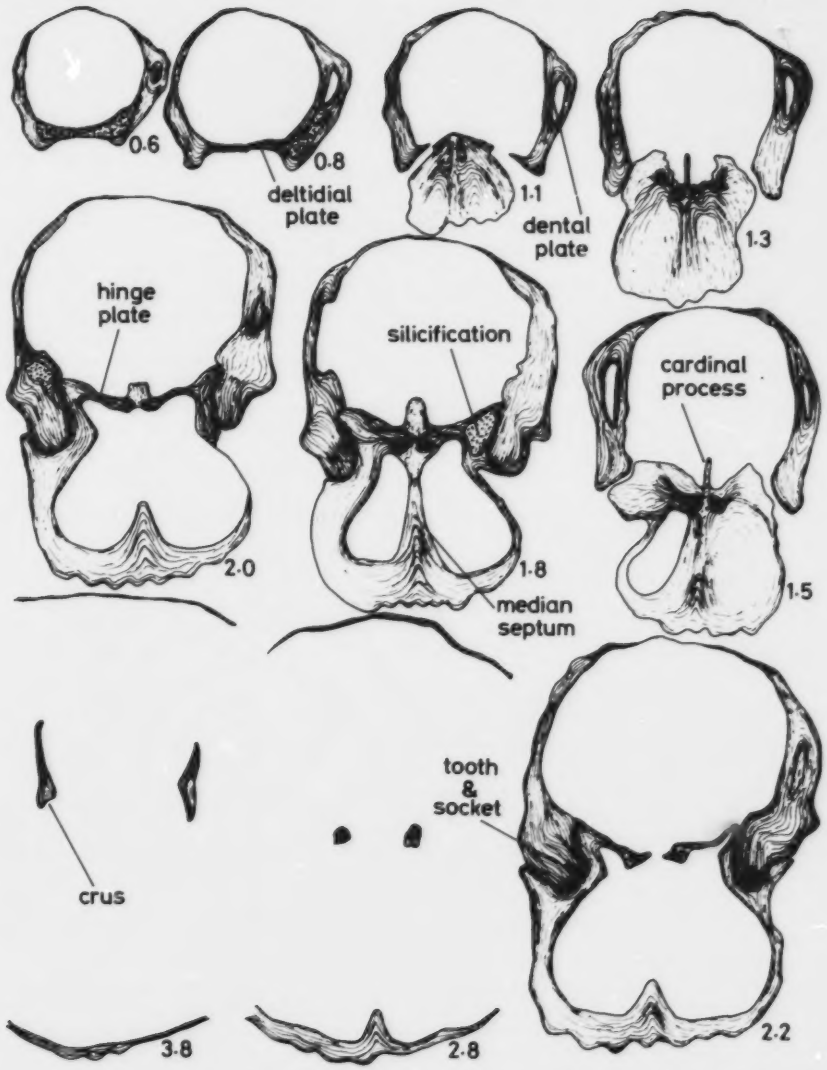

Figure 2.6. *Serial sections of* ***Hypsiptycha occidens*** *(Wilson, 1926), 0.6 to 3.8 mm from apex. Hypotype, GSC 91709, from the lower Beaverfoot Formation, south end of Table Mountain (GSC loc. 8026). Note the small dental cavities, poorly developed septalium, and an anteriorly thickened cardinal process, x12.5.*

Type specimens. Wilson selected and illustrated three types: GSC 6745 (a broken shell), GSC 6745 a, b (disarticulated pedicle and brachial valves) and GSC 6746 (a complete shell). These specimens are illustrated herein (Pl. 2.1, figs. 5-18). Wilson did not designate holotypes for her species; all the types, therefore, should be treated as syntypes; GSC 6746 is the best preserved and is selected herein as the lectotype. The types of *Rhynchotrema pisina* (Wilson, 1926) are a mixture of *Hypsiptycha occidens* and *Rostricellula pisina*.

Type locality and type stratum. "Richmond: Beaverfoot. Three-fourths of a mile east of Palliser pass and from the Stoddart Creek section, Windermere district, British Columbia" (Wilson, 1926, p. 22). GSC 6745 and GSC 6745 a, b are from Palliser Pass (GSC loc. 7563), GSC 6746 and GSC 6747 are from Stoddart Creek (GSC loc. 7800, 7801), but their precise stratigraphic positions cannot be determined. In the new collections, the species is restricted to the lower 100 m of the Beaverfoot Formation. Upper Ordovician.

Description. Shell small to medium-sized, elongate, subtriangular, unequally biconvex, with brachial valve deeper. Average length 9.9 mm, width 8.7 mm, thickness 6.2 mm (Fig. 2.5). Hingeline short, about one third of shell width. Anterior commissure denticulate, uniplicate.

Pedicle umbo narrow, high, weakly to moderately convex, with erect beak. Foramen small, rounded, mesothyridid. Delthyrium covered by medially conjunct deltidial plates (Pl. 2.2, fig. 2; Pl. 2.9, figs. 1, 2). Sulcus beginning 5-6 mm from apex, attaining about half shell width at anterior margin, bearing three, rarely two, simple costae. Brachial umbo more convex than pedicle umbo, with beak strongly curved into umbonal cavity of opposite valve. Fold commonly low, beginning 4 to 5 mm anterior of hingeline, bearing four, rarely three, simple costae. Each shell flank with five to six strong, simple costae. Concentric growth lamellae well developed, especially in anterior half of shell, about eight in 5 mm.

Dental plates low, thin, nearly fused to lateral shell wall (Fig. 2.6). Teeth relatively large, strong, supported by lateral shell wall. Muscle field small, restricted to umbonal region, poorly impressed, not clearly divided into adductor and diductor scars. Septalium poorly formed or absent. Hinge plates relatively large, divergent from each other at about 130°. Cardinal process septiform, distally thickened, with trilobate crest (Pl. 2.9, figs. 4, 5). Median septum well developed. Crural bases nearly in contact with each other posteriorly. Crura long, slender, radulifer.

Remarks. Hypsiptycha occidens is most similar to the Upper Ordovician *H. janea* (Billings, 1862) from Anticosti Island in its narrow, moderately convex pedicle umbo with tapering beak. *Hypsiptycha janea*, however, is represented by only one specimen, and its internal structures have not been examined (Jin, 1989). Internally, *H. occidens* resembles *H. anticostiensis* in its distally thickened cardinal process, long, slender crura, low, short dental plates, and lack of septalial plates. It differs from *H. anticostiensis*, in its much smaller, acutely triangular shell. The dental plates in *H. occidens* are nearly fused to the lateral shell wall (Pl. 2.1, fig. 18; Fig. 2.6).

Collections. Lower Beaverfoot Formation (total 83 specimens) GSC loc. 7563 (3 specimens, including 2 types from section about 1 km east of Palliser Pass; GSC loc. 7628 (6 specimens), section about 350 m east of Palliser Pass; GSC loc. 7800 (1 type), Stoddart Creek section; GSC loc. 7801 (8

specimens, including 1 type), Stoddart Creek section; GSC loc. 7933 (8 shell fragments), section at the head of Windermere Creek, 50 m from base of formation; GSC loc. 7954 (2 broken valves), section at the head of Windermere Creek, 72.5 m from base of formation; GSC loc. 7969 (15 specimens), western slope of 8400 ft. (2560 m) knoll between Mount Sir Douglas and Mount Munro; GSC loc. 8026 (21 specimens), near Brisco; GSC loc. 8042 (3 specimens), section 1.5 km north of Hatch Creek, 20 m from base of formation; GSC loc. 8047 (1 specimen), section 1.5 km north of Hatch Creek, about 45 m from base of formation; GSC loc. 45542 (4 specimens), Mount Sinclair section, 29.5-31 m from base of formation; GSC loc. 45612 (4 shell fragments), Mount Sinclair section, 61.5-64.5 m from base of formation; GSC loc. C-164501 (1 valve), Pedley Pass section, 21 m from base of formation; GSC loc. C-164503 (2 broken shells), Pedley Pass section, 40-44 m from base of formation; GSC loc. C-164524 (4 valves), Mount Sabine section, within lower 50 m of formation.

Hypsiptycha neenah (Whitfield, 1882)

Plate 2.2, figures 11-14

1882 *Rhynchonella neenah* Whitfield, p. 265, Pl. 12, figs. 19-22.
1893 *Rhynchonella*(?) *neenah* Whitfield; Winchell and Schuchert, p. 465, Pl. 34, figs. 35-37.
1949 *Hypsiptycha neenah* (Whitfield); Wang, p. 18, Pl. 10C, figs. 1-6.

Remarks. Only a brachial valve was collected and is assigned to *H. neenah* on the basis of its strong globosity, relatively high fold, and anteriorly weakened lateral costae within the fold. The brachial umbo is occupied by a shallow furrow, which changes into a fold at 5 mm from the apex. There are eight simple, subangular costae on each flank. Within the anterior 4 mm, each costa has a groove on the crest (Pl. 2.2, fig. 14).

The internal structures are not well preserved. A slightly thickened cardinal process is present. The median septum is relatively strong, extending for about one third of shell length.

Collection. Lower Beaverfoot Formation (25.4 m from base): GSC loc. 8041 (1 brachial valve), section 1.5 km north of Hatch Creek.

Genus *Lepidocyclus* Wang, 1949

Type species. Lepidocyclus laddi Wang, 1949, p. 13, Pl. 4D, figs. 10-14, 16. Upper Elgin Member, Maquoketa Formation. Upper Ordovician (Ashgill). Iowa.

Diagnosis. Shell medium-sized to large, strongly biconvex. Costae strong, growth lamellae imbricating. Pedicle umbo and beak incurved. Delthyrium covered by medially conjunct deltidial plates. Dental plates commonly reduced. Muscle field large, deep, flabellate in outline. Septalium small, with or without well delimited septalial plates. Hinge plates large, thick. Cardinal process thin, septiform. Crura radulifer.

Remarks. The genus is most similar to *Hypsiptycha* in its strong growth lamellae. *Hypsiptycha*, however, tends to have small and triangular shells with erect pedicle beaks.

Species assigned.

Rhynchotrema manniense Foerste, 1909
Lepidocyclus laddi Wang, 1949
Lepidocyclus erectus Wang, 1949
Lepidocyclus oblongus Howe, 1966
Lepidocyclus cooperi Howe, 1966

Species questionably assigned.

Rhynchotrema periamellosa Whitfield, 1877
Lepidocyclus rectangularis Wang, 1949
Lepidocyclus notatus Wang, 1949

The nature of deltidial plates in *R. periamellosa* and *L. notatus* is unknown (Amsden, 1983). The internal structures of *L. rectangularis* are not well known (Wang, 1949, p. 16); development of an erect pedicle beak, conjuct deltidial plates, and uniform growth lamellae, however, suggest a closer affinity to *Hypsiptycha* than to *Lepidocyclus*.

Age. Late Ordovician.

Lepidocyclus erectus Wang, 1949

Plate 2.4, figures 1-14

1949 *Lepidocyclus erectus* Wang, p. 15, Pl. 5B, figs. 1-9.
1962b *Rhynchotrema windermeris* Wilson; Norford, p. 18, Pl. 7, figs. 23, 25, 35 (*non* 22, 24).

Type specimens. Lepidocyclus erectus Wang, 1949. Holotype, SUI1834 (Pl. 5, figs. 6-9). Brainard Shale, Maquoketa Group. Upper Ordovician. Patterson's Spring, Iowa.

Description. Shell medium-sized, subpentagonal to subcircular, with brachial valve slightly deeper than pedicle valve. Hingeline short, attaining about one third of shell width. Anterior commissure denticulate, uniplicate.

Dimensions (mm).	Length	Width	Thickness
GSC 91683	17.5	17.0	13.4
GSC 91684	17.0	17.0	12.5

Pedicle umbo relatively narrow, high, uniformly convex, with suberect beak. Delthyrium covered by medially conjunct deltidial plates. Sulcus shallow to moderately deep, beginning 7 to 8 mm from apex, attaining about one half of shell width at anterior margin, and having three simple, rounded costae. Brachial umbo strongly convex, with umbonal median furrow changing into low fold about 5 mm anterior of hingeline. Each flank with ten to eleven simple, subrounded costae. Concentric growth lamellae strong, in some specimens spine-like, two in 1 mm at anterior margin.

Dental plates thin, fused to lateral shell wall posteriorly, becoming free anteriorly to form small dental cavities. Teeth supported by lateral shell wall. Muscle field small, not clearly divided into diductor and adductor scars. Septalium not well developed, with small septalial plates. Hinge plates relatively large, strongly divergent from each other. Cardinal process septiform. Median septum low, extending for about one third of shell length. Crura long, slender, radulifer or maniculifer (Pl. 2.4, fig. 14).

Remarks. The specimens are assigned to *L. erectus* on the basis of their high pedicle umbo, suberect beak, and medially conjunct deltidial plates. The type specimens from Iowa are slightly smaller (15.6 mm long and 15.3 mm wide) than those from the Rocky Mountains.

Collections. Lower Beaverfoot Formation (total 8 specimens) GSC loc. 42017 (3 specimens), Cirrus Mountain section, Alberta, 5.5-7 m above base of formation; GSC loc. 20014 (1 specimen), Mount Coleman section, Alberta, basal 35 m of formation; GSC loc. 45548 (3 specimens), Wonah Ridge section (Mount Sinclair), 10 m above base of the formation; GSC loc. C-137719 (1 shell), isolated outcrop: NTS 82 J E633200/N5550250.

Genus *Hiscobeccus* Amsden, 1983

Type species. Atrypa capax Conrad, 1842, p. 264, Pl. 14, fig. 21. Upper Ordovician, Richmond, Indiana (precise strata for the neotypes unknown, Amsden, 1983).

Diagnosis. Shell strongly costate and lamellose. Dental plates rudimentary or absent. Delthyrium open or with incipient deltidial plates. Hinge plates thick. Median septum thick. Cardinal process thin, septiform.

Species assigned.

Atrypa capax Conrad, 1842
Rhynchotrema rowleyi Foerste, 1920
Rhynchotrema kananaskia Wilson, 1926
Rhynchotrema windermeris Wilson, 1926
Lepidocyclus gigas Wang, 1949

Although Wang (1949) made no comments on the deltidial plates of *Lepidocyclus gigas*, his illustration (Pl. 10D, fig. 2) shows an open delthyrium. *Lepidocyclus gigas*, reported from the Bighorn Formation, Wyoming by Macomber (1970) and the Vaureal Formation, Anticosti Island by Jin (1989), also lacks medially conjunct deltidial plates.

Hiscobeccus kananaskia (Wilson, 1926)

Plate 2.3, figures 1-16

1926 *Rhynchotrema kananaskia* Wilson, p. 23, Pl. 4, figs. 14-18.
1962b *Rhynchotrema kananaskia* Wilson; Norford, p. 18, Pl. 7, figs. 16-20.
1969 *Rhynchotrema kananaskia* Wilson; Norford, p. 39 (no illustrations; his collections examined herein).

Type specimens. Wilson (1926) selected and illustrated three silicified shells as syntypes. Specimen GSC 6749 (Wilson, 1926, Pl. 4, figs. 14-16), labelled as "holotype" in Norford (1962b), is the best preserved of the three types and is selected herein as the lectotype.

Type locality and type stratum. "Richmond: Beaverfoot. From several localities east of Palliser pass, from the cherty beds northeast of mount McMurdo, Beaverfoot range, and from 95 feet above the base of the Beaverfoot at the head of Windermere creek, British Columbia" (Wilson, 1926, p. 23). In Wilson's list of localities, only the section 350 m east of Palliser Pass (GSC loc. 7628) is cited as the type locality. The three types are from the lower Beaverfoot Formation.

Description. Shell medium-sized, transverse, subtriangular to subcircular, nearly equibiconvex, or with slightly deeper brachial valve. Hingline curved, attaining one third to one half of shell width. Anterior commissure denticulate, uniplicate.

Dimensions (mm).	Length	Width	Thickness
Lectotype GSC 6749	15.0	16.1	9.8
Paralectotype GSC 6749a	13.8	16.3	10.4

Pedicle umbo low, rounded, moderately to strongly convex, with beak curved, but usually not appressed onto opposite umbo. Foramen small, permesothyridid. Delthyrium open. Sulcus shallow, beginning about 6 mm from apex, attaining one third to one half of shell width at anterior margin, with three simple costae. Brachial umbo weakly to moderately convex, occupied by shallow median furrow changing into fold 5 to 6 mm anterior of hingeline. Each shell flank with seven to ten simple, strong, subrounded costae. Concentric growth lamellae well developed, about one in 1 mm (Pl. 2.3, figs. 9, 15).

Dental plates poorly developed or absent. Teeth supported mainly by lateral shell wall. Muscle field well delimited. Septalium narrow at bottom, with low septalial plates. Hinge plates wide, thick, divergent from each other at 150 to 170°. Cardinal process low, septiform. Median septum relatively high, thick, extending for one third of valve length. Crura not preserved.

Remarks. Silicification has obscured the growth lamellae in most specimens. *Hiscobeccus kananaskia* is most similar to *H. capax* in its lack of medially conjunct deltidial plates. It differs from that species, however, in its lower convexity and weaker growth lamellae (see also Wilson, 1926, p. 23).

Collections. Lower Beaverfoot Formation (total 40 specimens) GSC loc. 5064 (3 specimens), Carbonate Creek section, 25 m above base of formation; GSC loc. 7563 (1 specimen), 1 km east of Palliser Pass; GSC loc. 7628 (3 types, near Palliser Pass); GSC loc. 7816 (2 specimens), near Harrogate; GSC loc. 7934 (3 specimens), Windermere Creek section, 29 m above base of formation; GSC loc. 7935 (1 fragment, identification uncertain), Windermere Creek section, 15 m above base of formation; GSC loc. 7969 (10 specimens), western slope of 8400 ft. (2560 m) knoll near Mount Sir Douglas; GSC loc. 8042 (2 specimens), section 1.5 km north of Hatch Creek, about 20 m above base of formation; GSC loc. 8043 (3 specimens), 1.5 km north of Hatch Creek, about 23 m above base of formation; GSC loc. 47432 (3 specimens), Tipperary Lake section, 3 to 7.5 m above base of formation; GSC loc. 52159 (2 fragments), section near Akutlak Creek, 118 m above base of formation; GSC loc. 57531 (2 specimens), 50°08.9'N, 115°07.9'W; GSC loc. C-164505 (1 specimen), Pedley Pass section, 56 m above base of formation; GSC loc. C-164506 (1 specimen), Pedley Pass section, 55 to 62 m above base of formation.

Hiscobeccus windermeris (Wilson, 1926)

Plate 2.2, figures 15-16; Plate 2.3, figure 17

1926 *Rhynchotrema windermeris* Wilson, p. 20, Pl. 4, figs. 1-4.
1962b *Rhynchotrema windermeris* Wilson; Norford, p. 18, Pl. 7, figs. 22, 24 (*non* 23, 25, 35).
1969 *Rhynchotrema windermeris* Wilson; Norford, p. 39 (no illustrations; his collections examined herein).

Type specimens. Wilson (1926) selected and illustrated three fragments as the types. These specimens, GSC 6744 and GSC 6744a, b, are fragile and very incomplete.

Type locality and type stratum. "Richmond: Beaverfoot. From the Stoddart Creek section of Windermere district, and northeast of mount McMurdo, Beaverfoot range, British Columbia" (Wilson, 1926, p. 21). The Stoddart Creek section is the type locality, as shown by the labels for the types. The specimens are from the lower Beaverfoot Formation (no precise stratigraphic position). Upper Ordovician.

Description. Shell large, subtriangular to subcircular, nearly equibiconvex, or with slightly deeper brachial valve. Largest shell fragment 34 mm wide. Hingeline curved, attaining one quarter to one third of shell width. Anterior commissure denticulate, uniplicate.

Pedicle umbo low, rounded, strongly and uniformly convex, with beak appressed onto opposite umbo. Delthyrium not well exposed because of strongly curved pedicle umbo. Deltidial plates rudimentary or absent. Sulcus broad, well delimited, beginning 7 to 8 mm from beak, attaining about one half of shell width at anterior margin, and bearing three simple, subrounded costae. Brachial umbo moderately to strongly convex, marked by minute median furrow. Fold rising from furrow about 5 to 6 mm anterior of hingeline, bearing four simple, subrounded costae. Median intercostal groove deeper and wider than other grooves.

Dental plates present, posteriorly attached to lateral shell wall. Teeth relatively large, crescent-shaped. Muscle field relatively large, weakly striated. Septalium small. Cardinal process septiform. Median septum well developed. Crura not preserved.

Remarks. Wilson (1926) mentioned "large deltidial plates . . . so poorly preserved that it is impossible to distinguish the line of amalgamation." No deltidial plates are evident in her illustrations of the species, nor are they distinguishable in the broken type specimens. In the newly collected specimens, no deltidial plates were observed.

Hiscobeccus windermeris is distinguished from *H. kananaskia* by its much larger and commonly more convex shell.

Collections. Lower Beaverfoot Formation (total of 11 specimens) GSC loc. 5064 (1 broken p.v.), Carbonate Creek section, northeast of McMurdo, 25 m above base of formation; GSC loc. 7801 (1 broken p.v.), Stoddart Creek section; GSC loc. 7932 (1 fragment of b.v. and 2 fragments of p.v.), head of Windermere Creek, 81 m above base of formation; GSC loc. 20014 (1 specimen), Mount Coleman section, Alberta, basal 35 m of formation; GSC loc. 45579 (1 specimen), section near Akutlak Creek, 30 m above base of formation; GSC loc. 45612 (2 specimens), Mount Sinclair section; GSC loc. 52168 (1 fragment of p.v.), Pipestone River section, Alberta; GSC loc. C-164504 (3 fragments), Pedley Pass section, 55 to 62 m above base of formation.

Genus *Stegerhynchus* Foerste, 1909

Type species. Rhynchonella (Stegerhynchus) whitii-praecursor (= *Stegerhynchus praecursor*) Foerste, 1909, p. 96, Pl. 3, figs. 47a-c. Clinton Bed, Clifton, Tennessee. Jones (1981) cleared up much of the confusion over the genus by confirming *S. praecursor* as the type species for *Stegerhynchus*. Previously, *Rhynchonella whitii* Hall (1863) has been commonly, but incorrectly, quoted as the type species (see, for example, Cooper, 1956, and Cocks, 1978). The clarification is critical for classification, as *R. whitii* is devoid of a cardinal process, whereas *S. praecursor* possesses a high, blade-like cardinal process.

Diagnosis. Shell small to medium-sized. Pedicle umbo narrow, with erect to suberect beak. Delthyrium open or with rudimentary deltidial plates. Costae strong, angular to subangular. Dental plates short. Septalium small, with poorly developed septalial plates. Median septum high, raising septalium to level of hingeline. Cardinal process high, septiform. Crura radulifer.

Species assigned.

Terebratula borealis von Buch, 1834
(= *Ferganella chattertoni* Lenz, 1977; see Jones, 1981)
Rhynchonella vicina Billings, 1866
Stegerhynchus whitii-praecursor Foerste, 1909
(= *S. cliftonensis* Foerste, 1909; see Jones, 1981)
Camarotoechia concinna Savage, 1913
Camarotoechia peneborealis Twenhofel, 1928

Species questionably assigned.

Terebratula diadonta Dalman, 1828
Rhynchonella pusilla J. de C. Sowerby, 1839 (see Temple, 1987: *Stegerhynchus pusillum*)
Camarotoechia antiqua Savage, 1913
Stegerhynchus decemplicatus angaciensis Chernychev, 1937
Ferganella lincolnensis Johnson, 1964
Stegerhynchus claritense Amsden, 1968
Stegerhynchus estonicus Rubel, 1977

Temple (1987) transferred the Lower Llandovery species from Wales, *Rhynchonella pusilla* (J. de C. Sowerby, 1839), from *Rhynchotrema* (in Temple, 1970; Cocks, 1978) to *Stegerhynchus*, but he made no comment on the morphology of the cardinal process and septalium.

Cocks (1978) assigned several other species to *Stegerhynchus* without commenting on their internal structures and considered *Rhynchonella whitii* Hall to be the type species for the genus.

Age. Early Silurian – Late Silurian.

Stegerhynchus praecursor Foerste, 1909

Plate 2.5, figures 11-19; Figure 2.7

1909 *Rhynchonella (Stegerhynchus) whitii-praecursor* Foerste, p. 96, Pl. 3, figs. 47a-c.
1909 *Rhynchonella (Stegerhynchus) neglecta-cliftonensis* Foerste, p. 97, Pl. 3, figs. 48a-c.
1965 *Stegerhynchus praecursor* Foerste; Schmidt and McLaren, p. 556, figs. 422 (5a-b).
1978 *Stegerhynchus cliftonensis* Foerste; Amsden, Pl. 11, figs. 1-9.
1981 *Stegerhynchus praecursor* Foerste; Jones, p. 104, Figs. 3a-n.

Type specimens. The type specimens originally figured by Foerste as *R. (S.) whitii-praecursor* have not been found in the U.S. National Museum (Amsden, 1978, p. 28; Jones, 1981, p. 104). The types were collected from the Clinton Bed, Clifton, Tennessee (Foerste, 1909, p. 97).

Description. (Based on Rocky Mountains collections.) Shell small, subtriangular to subcircular, slightly elongate to transverse, nearly equibiconvex (Fig. 2.7). Hingeline short,

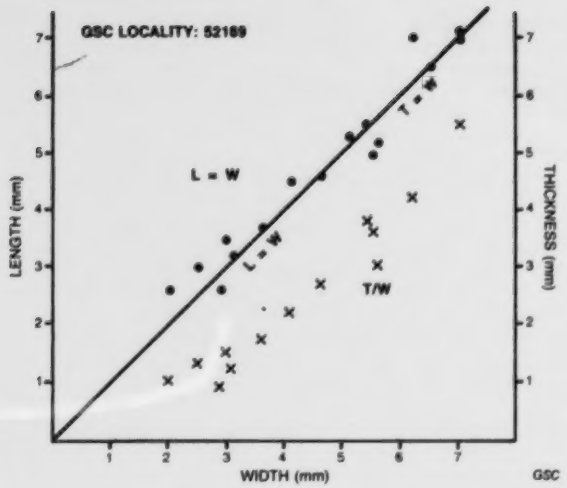

Figure 2.7. *Shell dimensions of* ***Stegerhynchus praecursor*** *Foerste, 1909. The sample is from the upper Beaverfoot Formation (318 m above the base), at a section 1.5 km north of Hatch Creek (GSC loc. 52169). Note the shell convexity remains little changed during ontogeny.*

commonly less than one third of shell width. Commissure denticulate around anterior margin.

Pedicle umbo weakly to moderately convex, noncarinate, with beak suberect or incurved but not appressed onto opposite umbo. Delthyrium open. Sulcus shallow but well delimited, beginning 2.5 to 3.5 mm from apex, bearing two simple, subangular costae. Brachial umbo weakly to moderately convex. Fold low, beginning 2 mm anterior of hingeline, commonly bearing three, rarely two, costae.

Dental plates not well developed. Muscle field not clearly delimited in etched-out valves. Septalium poorly formed. Hinge plates small, narrow. Cardinal process thin, septiform (Pl. 2.5, fig. 17). Median septum low, extending about one third of shell length. Crura relatively short, radulifer.

Remarks. The Rocky Mountains collections are mostly young specimens, as indicated by the lack of fully developed fold and sulcus in shells smaller than 6 mm in length. The specimens illustrated by Foerste (1909, Pl. 3, figs. 47A-47C) average 8 mm long and 9 mm wide. The topotypes (see Jones, 1981, Fig. 3) are on average 6 mm long and 7 mm wide. The largest specimens from the Rocky Mountains reach the average size of the types (Fig. 2.7). In the etched-out valves, no dental plates are preserved.

Collections. Upper Beaverfoot Formation (total of 31 specimens) GSC loc. 23859 (1 p.v.), peak near Moscow Creek, near top of formation; GSC loc. 45541 (1 specimen), Mount Sinclair, 348 m above base of formation; GSC loc. 45602 (4 specimens), section 1.5 km north of Hatch Creek, 309 m above base of formation; GSC loc. 47400 (2 fragments), Pedley Pass section, 363 m above base of formation; GSC loc. 52169 (22 specimens), section 1.5 km north of Hatch Creek, 318 m above base of formation; GSC loc. 52170 (1 specimen), section 1.5 km north of Hatch Creek, 237 m above base of formation.

Stegerhynchus borealis (von Buch, 1834)

Plate 2.5, figures 1-10

1832 ***Terebratula borealis*** Schlotheim, p. 65 (*nomen nudum*).
1834 ***Terebratula borealis*** von Buch, p. 87. (Type specimen chosen as the one figured in Schlotheim, 1832: ***Anomia Terebratula lacunosus*** Linneaus, p. 68, Pl. 20, figs. 6a-c).
1867 ***Rhynchonella borealis*** (Schlotheim); Davidson, p. 174, Pl. 21, figs. 14-15, 17-20, 24-25, (*non* 16, 26-27).
1937 ***Camarotoechia borealis*** (von Buch); St. Joseph, p. 33, Figs. 1-15.
1967 ***Ferganella borealis*** (Schlotheim); Kul'kov, p. 76, Pl. 7, figs. 7-11, Fig. 31.
1975 ***Stegerhynchus borealis*** (Schlotheim); Oradovskaya, p. 87, Pl. 66, figs. 2-5.
1976 ***Ferganella borealis*** (Schlotheim); Sheehan, p. 729, Pl. 5, figs. 1-5.
1977 ***Ferganella chattertonia*** Lenz, p. 1542, Pl. 8, figs. 1-16.
1977 ***Stegerhynchus estonicus*** Rubel (in Rubel and Rozman), p. 220, Pl. 4, figs. 7-10, Pl. 5, figs. 1-2, Pl. 6, figs. 1-3, Pl. 7, figs. 1-6.
1981 ***Stegerhynchus borealis*** (von Buch); Jones, p. 102, 108, Pl. 19, figs. 1-18, 22-30, 37-39, Pl. 20, figs. 1-8.
1982 ***Ferganella borealis*** (Schlotheim); Fu, p. 141, Pl. 39, fig. 1, Fig. 35.

Type specimens. The lectotype was selected by St. Joseph (1937a) as the one figured by Schlotheim (1832, Pl. 20, figs. 6a-c), deposited in the Paleontological Institute and Museum of Berlin University.

Type locality and type stratum. Gotland, Wenlock. The type locality and type horizon were not defined precisely by the original or subsequent authors. The lectotype was obtained from the Encriniten-Übergangskalkstein beds of Gotland, of Wenlock age (St. Joseph, 1937a; Bassett and Cocks, 1974).

Description. (Based on Rocky Mountains collections.) Shell small, transverse, subcircular, unequally biconvex, with deeper brachial valve. Hingeline curved, attaining about one third of shell width. Anterior commissure denticulate, uniplicate.

Dimensions (mm).	Length	Width	Thickness
GSC 9168	8.5	9.0	7.0
GSC 9167	5.5	6.7	3.5

Pedicle umbo narrow, weakly convex, with incurved beak in relatively large and strongly convex forms. Delthyrium open. Sulcus well formed, beginning about 4 mm from apex, commonly bearing three, rarely four, costae. Brachial umbo marked by minute median furrow. Fold low, beginning about 3 mm anterior of hingeline, commonly carrying four subangular costae. Bifurcation and intercalation of costae rare. Concentric growth lines not well preserved.

Collections. Nonda Formation (total of 31 specimens) GSC loc. 43586 (2 specimens), near Lapie Lake, 59°19'00"N, 126°16'00"W; GSC loc. 45558 (2 specimens), Mount St. George section, 68 m above base of formation; GSC loc. 64523 (1 specimen), Tuchodi River section, 180 m above base (near top) of formation; GSC loc. 64544 (13 specimens), Toad River Bridge section, 287.5 to 293 m above base of formation; GSC loc. 64549 (13 specimens), Toad River Bridge section, 134.5 to 138.5 m above base of formation.

Stegerhynchus concinna (Savage, 1913)

Plate 2.5, figures 20-24

1913 *Camarotoechia*(?) *concinna* Savage, p. 127, Pl. 7, figs. 4-5.
1974 *Stegerhynchus concinna* (Savage); Amsden, p. 66, Pl. 14, figs. 3-4, Pl. 15, figs. 1-3.
1981 *Stegerhynchus concinna* (Savage); Jones, p. 103, Pl. 18, figs. 1-15.

Type specimens. The lectotype, UIX-855, was selected and illustrated by Amsden (1974).

Type locality and type stratum. Near Edgewood, Pike County, Missouri. Edgewood Group (Lower Llandovery).

Description. (Based on Rocky Mountains collections.) Shell small, subtriangular to subcircular, with brachial valve slightly deeper than pedicle valve. Hingeline short, curved, attaining about one quarter to one third of shell width. Anterior commissure sharply denticulate, uniplicate.

Dimensions (mm).	Length	Width	Thickness
GSC 91691	9.4	10.2	6.9

Pedicle umbo low, narrow, moderately convex, with suberect beak. Delthyrium open. Sulcus flanked by a pair of strong, subangular costae, with median costa bifurcating 2 to 3 mm from apex. Brachial umbo more convex than pedicle umbo. New costae becoming intercalated on both sides of median costa 2 mm anterior of hingeline. Each flank bearing four to five coarse, angular to subangular costae. Bifurcation and intercalation rare, except in sulcus and on fold.

Remarks. The Nonda specimens are mostly fragmentary shells, silicified, recrystallized, and reveal no internal structures. Only in one shell with a broken posterior is a cardinal process observed. They are assigned to *S. concinna* mainly on the basis of their external morphology. Distinction of *S. concinna* and *S. praecursor* is based mainly on external features. *Stegerhynchus concinna* has one to three costae in the sulcus, whereas *S. praecursor* has one or two in the sulcus. Moreover, *S. concinna* tends to have anteriorly inflated costae (Amsden, 1974, Pl. 14, figs. 3-4, Pl. 15, figs. 1-3; Jones, 1981, Fig. 3, Pl. 18, figs. 1-15).

Collections. Nonda Formation (total of 11 specimens) GSC loc. 64516 (11 specimens), Gathto Creek section, 188 m above base of formation.

Stegerhynchus peneborealis (Twenhofel, 1928)

Plate 2.6, figures 1-5

1928 *Camarotoechia peneborealis* Twenhofel, p. 211, Pl. 19, figs. 7-9.
1972 *Stegerhynchus* sp. cf. *S. peneborealis* (Twenhofel); Bolton, Pl. 8, figs. 4-5, 10.
1981 *Stegerhynchus* sp. cf. *S. peneborealis* (Twenhofel); Bolton, Pl. 3, fig. 20.
1989 *Stegerhynchus peneborealis* (Twenhofel); Jin, Pl. 7, figs. 6-21, 30; Pl. 26, fig. 3.

Type specimens. Specimen YPM 10422 figured in Twenhofel (1928) was selected as the lectotype by Jin (1989).

Type locality and type stratum. Anse Gibbons, Anticosti Island. Jupiter Formation (Upper Llandovery).

Description. (Based on Rocky Mountains collections.) Shell medium-sized, strongly transverse (12.8 mm long, 17.2 mm wide, 9.8 mm thick), subpentagonal, unequally biconvex, with deeper brachial valve. Hingeline relatively long, attaining two thirds of shell width. Anterior commissure strongly denticulate, uniplicate.

Pedicle umbo narrow, weakly convex, noncarinate, extending beyond hingeline for 1.5 mm, with suberect beak. Delthyrium open. Sulcus sharply delimited, beginning 5 mm from apex, occupying one half of shell width at anterior margin, and bearing three angular costae. Brachial umbo strongly convex, with beak buried in delthyrial cavity. Minute median furrow occupying umbo, changing into low fold about 4 mm anterior of hingeline. Four angular costae occupying fold. Each flank with six angular costae. Growth lines obscured by silicification.

Collection. Beaverfoot Formation. GSC loc. C-137715 (1 complete specimen), creek north of Mount Harrison, NTS 82 J 633800E, 5552700N.

Family ORTHORHYNCHULIDAE Cooper, 1956

Diagnosis. Costae strong, beginning from apex. Fold and sulcus vaguely to sharply defined. Interareas well delimited in most genera. Delthyrium open or covered with conjunct deltidial plates. Dental plates commonly reduced. Septalium sessile or supported by low median septum. Cardinal process septiform, multilobatiform, or branching. Crura radulifer or prefalcifer.

Genera included.

Orthorhynchula Hall and Clarke, 1893
Callipleura Cooper, 1942
Machaeraria Cooper, 1955
Latonotoechia Havliček, 1960
Sicorhyncha Havliček, 1961
Orthorhynchuloides Williams, 1962
Zlichorhynchus Havliček, 1963
Thliborhynchia Lenz, 1967
Tuvaerhynchus Kul'kov, 1985
Orthorhynchyllion Jin, 1989
Gnamptorhynchos Jin, 1989

Remarks. The orthorhynchulids differ from the rhynchotrematids in several important features. For example, *Orthorhynchula*, *Callipleura*, *Tuvaerhynchus*, *Gnamptorhynchos*, and *Orthorhynchyllion* have prominent interareas on both valves, with apsacline orientation of the cardinal area. The septiform cardinal process may be modified into a crinkled myophore (as in *Machaeraria*), a branching form (as in *Orthorhynchyllion*), or even a multilobate form (as in *Gnamptorhynchos*). Other genera, such as *Latonotoechia*, and *Thliborhynchia* (see Johnson, 1975 for serial sections), do not exhibit interareas, but have reduced dental plates and sessile septalium.

Age. Middle Ordovician - Middle Devonian.

Genus *Gnamptorhynchos* Jin, 1989

Type species. Gnamptorhynchos inversum Jin, 1989. Prinsta Member, Ellis Bay Formation. Upper Ordovician. Anticosti Island.

Diagnosis. Shell medium-sized, strongly convex. Costae angular to subangular. Pedicle umbo moderately convex, with small incurved beak. Interareas prominent, apsacline. Delthyrium open. Pedicle sulcus deep, commonly containing three costae. Brachial umbo strongly convex. Fold high and sharply delimited. Dental plates well developed. Teeth slender, with accessory teeth and sockets. Septalium relatively large. Cardinal process multilobate. Crura short, prefalcifer.

Remarks. Gnamptorhynchos is similar to *Orthorhynchula* in its strong costae, well developed apsacline interarea of the pedicle valve, and sharp sulcus and fold. Internally, *Gnamptorhynchos* differs from other orthorhynchulid genera in its accessory teeth and sockets, multilobate cardinal process, prefalcifer type of crura, and a septalium, which may be sessile or supported by two low ridges.

Species assigned

Gnamptorhynchos inversum Jin, 1989
Gnamptorhynchos selliseptalicium Jin, 1989

Age. Late Ordovician - Early Silurian.

Gnamptorhynchos inversum Jin, 1989

Plate 2.6, figures 6-16

1989 *Gnamptorhynchos inversum* Jin, Pl. 10, figs. 6-15, Pl. 11, figs. 1-10, Pl. 27, figs. 1-4.

Type specimens. Holotype GSC 102447, paratypes GSC 102448, GSC 102445, GSC 102446, and GSC 102449. Prinsta Member, Ellis Bay Formation. Uppermost Ordovician. Lousy Cove, northeast Anticosti Island, Quebec.

Remarks. Only three specimens of *G. inversum* have been collected from the Rocky Mountains. The specimens are assigned to the species on the basis of their well developed interareas in both valves, sharply delimited fold and sulcus beginning from apices of the valves, accessory sockets, and short crura.

Dimensions (mm).	Length	Width	Thickness
GSC 91693	10.6	10.0	8.0
GSC 91694 (b.v.)	16.0	16.1	8.7 (depth)

Costae are strong, subrounded, with seven on each flank. In the umbonal parts, the fold has two costae, which bifurcate to become four anteriorly; the sulcus has two, which are intercalated by a median costa anteriorly. The dental plates enclose a low, platform-like muscle field (Pl. 2.6, fig. 16). In the etched-out valves, only a median lobe of the cardinal process is preserved (Pl. 2.6, fig. 14).

Collections. Lower Beaverfoot Formation (total of 3 specimens) GSC. loc. 7969 (1 p.v.), western slope of 8400 ft. (2560 m) knoll near Mount Sir Douglas; GSC loc. 32302 (1 b.v.), isolated outcrop, 49°50'38"N, 115°26'46"W; GSC loc. C-147466 (1 shell), north flank of Russell Peak, NTS 82 J 624900E, 5589600N, basal 5 m of formation.

Gnamptorhynchos sp.

Remarks. Fragments of one shell are assigned to *Gnamptorhynchos* sp. The basis for so doing lies in the apsacline cardinal area, sharply delimited fold and sulcus beginning from the apices, and dental plates enclosing a platform-like muscle field. The natures of the cardinal process and crura are unknown.

Collection. Upper Beaverfoot Formation. GSC loc. 52170 (1 shell separated into two valves), section 1.5 km north of Hatch Creek, 257 m above base of formation.

Family TRIGONIRHYNCHIIDAE McLaren, 1965

Diagnosis. Shell small to medium-sized. Costae commonly simple, angular to subrounded, beginning from apex. Delthyrium open or covered by deltidial plates. Dental plates present. Septalium well formed, open to partly or completely capped by cover-plate. Cardinal process absent. Crura commonly radulifer.

Genera assigned. In addition to the genera listed by Schmidt and McLaren (1965), the following Ordovician-Silurian genera are assigned:

Rhynchotreta Hall, 1879
Virginiata Amsden, 1968
Evenkorhynchia Rozman, 1969
Hemitoechia Nikiforova, 1970
Lenatoechia Nikiforova, 1970
Microsphaeridiorhynchus Sartenaer, 1970
Thebesia Amsden, 1974
Hercotrema Jin, 1989

Age. Middle Ordovician - Early Carboniferous.

Genus *Rostricellula* Ulrich and Cooper, 1942

Type species. Rostricellula rostrata Ulrich and Cooper, 1942. Wardell Formation, Middle Ordovician, Tennessee.

Diagnosis. Shell small to medium-sized. Pedicle sulcus and brachial fold developed anteriorly. Costae strong, simple. Delthyrium open or partly covered by rudimentary deltidial plates. Dental plates well developed. Septalium small. Median septum strong. Cardinal process absent. Crura radulifer.

Remarks. Evenkorhynchia Rozman (1969, 1979) is similar to *Rostricellula* in internal structures, the only morphological difference is that the median costae in *Evenkorhynchia* show bifurcation and intercalation (see also A.G. Yadrenkina, not individually cited in Moskalenko, 1984, p. 56).

Species assigned. Apart from the species of *Rostricellula* described by Cooper (1956), the following species have been assigned in recent years.

Terebratula ambigena Barrande, 1847 (see Havlíček 1961: *Rostricellula ambigena* Barrande)
Rostricellula subrostrata Nikiforova, 1955
(= *Rostricellula colei* Cooper, 1956)
Rostricellula sibirica Rozman, 1979
Rostricellula elongata Fu, 1982

Age. Middle Ordovician - Early Silurian.

Rostricellula pisina (Wilson, 1926)

Plate 2.6, figures 17-24; Plate 2.7, figures 1-9

1926 *Rhynchotrema pisina* Wilson, p. 22, Pl. 4, figs. 11-12 (*non* 13).

Type specimens. Wilson (1926) selected and illustrated three types: GSC 6747 (Wilson, 1926, Pl. 4, fig. 13), GSC 6747a (Wilson, 1926, Pl. 4, fig. 12), and GSC 6748 (Wilson, 1926, Pl. 4, fig. 11). These specimens are a mixture of *Rostricellula pisina* (GSC 6747a and GSC 6748) and *Hypsiptycha occidens* (GSC 6747). GSC 6747a is the better preserved of the two syntypes of *R. pisina* and is selected herein as the lectotype.

Type locality and type stratum. "Richmond: Beaverfoot. From the chert beds of the Beaverfoot range, from the Fairmont Springs and the Stoddart Creek sections, Windermere district, British Columbia" (Wilson, 1926, p. 22). The lectotype is from the Stoddart Creek section (GSC loc. 7800), and the paralectotype from the Carbonate Creek section (GSC loc. 5064). Both types are from the lower Beaverfoot Formation, Upper Ordovician.

Description. Shell small, triangular, suboval, nearly equibiconvex. Hingeline relatively short, attaining about one third of shell width. Anterior commissure denticulate, uniplicate.

Dimensions (mm).	Length	Width	Thickness
GSC 91696	9.5	10.6	8.0
GSC 91697	9.7	10.3	7.8

Pedicle umbo low, rounded, strongly convex, noncarinate, with beak incurved but not appressed onto opposite umbo. Delthyrium open or with rudimentary deltidial plates. Sulcus shallow, well delimited only in anterior half of valve, carrying three simple, subrounded costae. Brachial umbo rounded, convex, marked by small median furrow. Fold low, becoming well defined anteriorly. Each shell flank with six to seven simple, subrounded costae. Growth lines not preserved. Interior intensely silicified and recrystallized. A polished section through the posterior of a brachial valve failed to reveal the presence of a cardinal process.

Remarks. Wilson (1926) described shell growth lamellae and a small cardinal process in *R. pisina.* However, this was based on the type specimen, GSC 6747, which is now transferred to *Hypsiptycha occidens.* The Rocky Mountains specimens are assigned to *Rostricellula pisina* on the basis of their commonly small, transverse, and globose shell, suberect to weakly incurved pedicle beak, and lack of cardinal process.

Collections. Lower Beaverfoot Formation. GSC loc. 43940 (4 specimens), ridge between Bull River and Quinn Creek.

Genus *Lepidocycloides* Nikiforova, 1961

Type species. Lepidocycloides baikiticus Nikiforova, 1961, p. 213, Pl. 41, figs. 1-15. Upper Ordovician (Dolbar Stage), Siberian Platform.

Diagnosis. Shell commonly strongly convex, costellate to costate, lamellose. Dental plates well developed. Septalium restricted at opening. Hinge plates large. Median septum well formed. Crura radulifer.

Remarks. Rozman (1969) proposed a new subfamily, the Rostricellulinae, consisting of *Rostricellula* Ulrich and Cooper, 1942, *Lepidocycloides* Nikiforova, 1961, and *Evenkorhynchia* Rozman, 1969. He assigned the subfamily to the Rhynchotrematidae rather than the Trigonirhynchiidae because these genera lack a covered septalium. But *Lepidocycloides* is also without a cardinal process, which is a diagnostic feature of the Rhynchotrematidae. Baranov (1980) included *Lepidocycloides* in his new family, the Innaechiidae, in which many of the genera have smooth shells posteriorly and marginal spines. Nikiforova and Andreeva (1961) and Rozman (1969, 1979), however, described *Lepidocycloides* as ribbed from the beaks and lacking marginal spines. Although the septalium in *Lepidocycloides* is not completely covered by a plate, it is usually restricted by crural ridges projecting into the septalial cavity (Nikiforova and Andreeva, 1961, figs. 24-25; this paper, Fig. 2.8). *Lepidocycloides* seems, therefore, to be closest to the genera of the Trigonirhynchiidae and is retained within that family in the present study.

Species assigned.

Lepidocycloides baikiticus Nikiforova, 1961
Lepidocycloides gravis Nikiforova, 1961
Lepidocycloides nana Rozman, 1979
Lepidocycloides indivisus indivisus Rozman, 1979
Lepidocycloides indivisus striatus Rozman, 1979
Lepidocycloides rudicostatus n. sp.

Lepidocycloides rudicostatus n. sp.

Plate 2.7, figures 10-19; Plate 2.9, figures 9-11; Figure 2.8

Derivation of name. From the Latin *rudi,* coarse, and *costatus,* ribbed. The word, *rudicostatus,* is a masculine adjective.

Type specimens. Three calcareous shells: holotype, GSC 91698; paratypes, GSC 91699 and GSC 91710 (the last serially sectioned) (Pl. 2.7, figs. 10-19, Fig. 2.8).

Type locality and type stratum. GSC loc. 8026, isolated outcrop near Brisco. Beaverfoot Formation.

Diagnosis. Large, moderately convex shells of *Lepidocycloides* with strong costae and growth lamellae. Triangular septalium restricted at opening by crural ridges.

Description. Shell large, subtriangular to subcircular, nearly equibiconvex. Hingeline curved, attaining about one half of shell width. Anterior commissure strongly denticulate, uniplicate.

Dimensions (mm).	Length	Width	Thickness
GSC 91698	25.0	26.4	17.6
GSC 91699	25.3	25.3	15.8

Pedicle umbo rounded, strongly convex, noncarinate, with beak appressed onto opposite umbo. Delthyrium open or with rudimentary deltidial plates. Sulcus wide, relatively shallow, beginning about 7 mm from apex, attaining one half of shell width at anterior margin, bearing three simple, subrounded costae. Brachial umbo strongly convex, with beak buried in umbonal cavity of pedicle valve. Fold low, well delimited, beginning 5 to 6 mm anterior of hingeline, carrying four costae. Each shell flank with eight to nine simple, subrounded costae. Growth lamellae present but not well preserved (Pl. 2.7, figs. 14, 15).

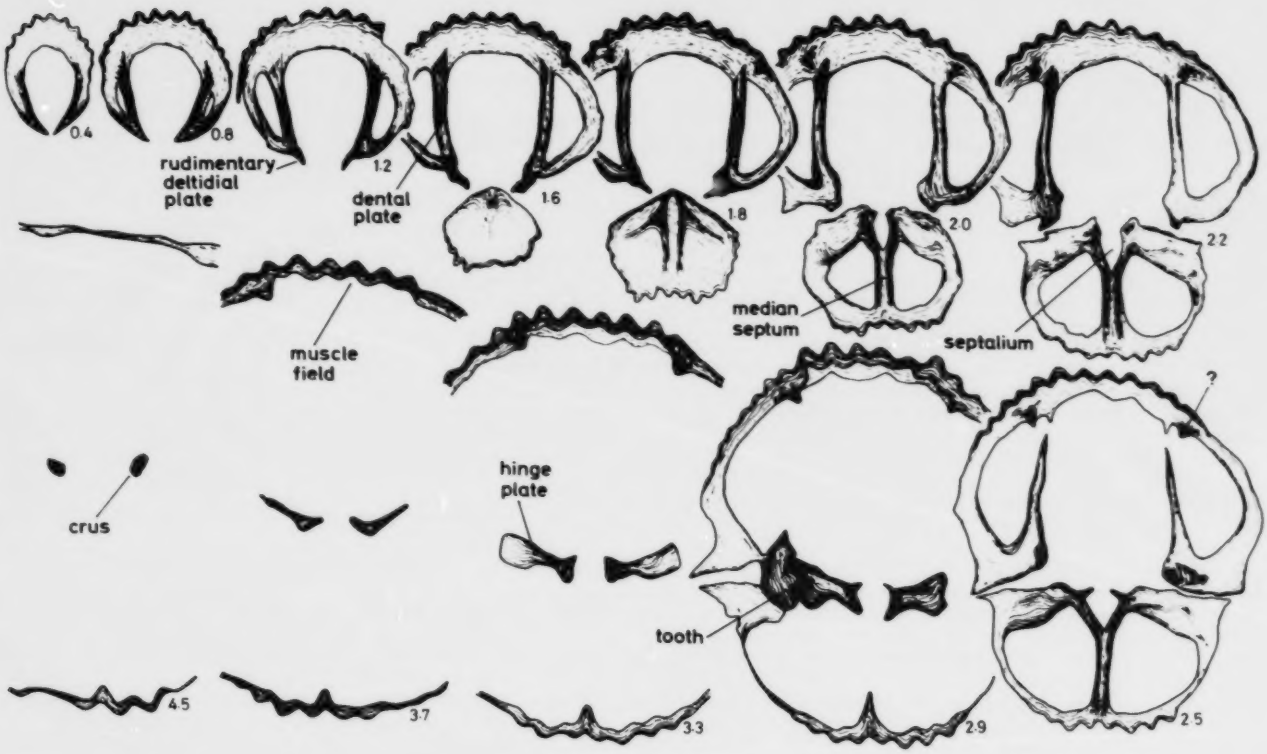

Figure 2.8. *Serial sections of* ***Lepidocycloides rudicostatus*** *n. sp., 0.4 to 4.5 mm from apex. Paratype GSC 91710, from the lower Beaverfoot Formation, near Brisco (GSC loc. 8026). Note the well developed septalial plates and median septum in the brachial valve, x5.*

Dental plates high, thin. Teeth moderately large. Muscle field shallow. Septalium narrow, relatively deep, with well developed septalial plates. Septalial opening restricted by crural bases projecting into septalium (Pl. 2.9, fig. 11). Hinge plates small, thin. Median septum high, relatively thin (Pl. 2.9, fig. 10). Cardinal process absent. Crura slender, radulifer.

Remarks. The new species is assigned to *Lepidocycloides* on the basis of the relatively large shell with growth lamellae, rudimentary deltidial plates, and lack of cardinal process. It differs from the Upper Ordovician *Lepidocycloides baikiticus* and *L. gravis* from Siberia in its larger size, less globose profile, stronger costae, and deeper, narrower septalium. *Lepidocycloides baikiticus* and *L. gravis* have very short dental plates, a small, shallow septalium, and a low median septum.

Collections. Lower Beaverfoot Formation. GSC loc. 8026 (5 specimens, including 1 set of serial sections), near Brisco.

Genus *Hercotrema* Jin, 1989

Type species. Hercotrema bulbicostatum Jin, 1989. Richardson Member, Jupiter Formation. Upper Llandovery. Anticosti Island, Quebec.

Diagnosis. Shell small to medium-sized. Costae strong, simple. Pedicle sulcus and brachial fold well developed anteriorly. Delthyrium open or with rudimentary deltidial plates. Dental plates high, thin. Septalium small to moderately large, commonly with restricted opening. Cardinal process absent. Crura radulifer or maniculifer.

Remarks. Hercotrema is characterized by delicate dental plates and crural plates, a restricted septalial cavity, and a lack of cardinal process. *Lenatoechia* Nikiforova, 1970, assigned doubtfully to the Trigonirhynchiidae (see Nikiforova and Popov, 1981), resembles *Hercotrema* in general morphology but differs in its apsacline pedicle interarea and thickened internal structures (Nikiforova and Andreeva, 1961, Figs. 19, 20).

Species assigned.

Terebratula Daphne Barrande, 1847
Terebratula Nympha Barrande, 1847
Terebratula Nympha var. *pseudolivonica* Barrande, 1847
Rhynchonella infelix Barrande, 1879
Camarotoechia winiskensis Whiteaves, 1906
Camarotoechia pahranagatensis Waite, 1956
Stegerhynchus incohans Havliček, 1961
Ancillotoechia borealis Lenz, 1974
Ancillotoechia berryi Sheehan, 1976
Ancillotoechia perryi Sheehan, 1982
Hercotrema bulbicostatum Jin, 1989
Hercotrema humiliseptatum n. sp.

The four species described by Waite (1956), Lenz (1974), and Sheehan (1976, 1982) are characterized by a septalium with its opening restricted (not completely capped) by medially projecting crural bases, and by a lack of cardinal process.

Age. Early Silurian - Early Devonian.

Hercotrema humiliseptatum n. sp.

Plate 2.8, figures 1-11, 14, 15; Figure 2.9

Derivation of name. Latin *humili*, low; *septatum*, neuter, perfect past participle of *septum*, partitioned. Note that both *Hercotrema* and *humiliseptatum* are neuter.

Type specimens. Four silicified specimens: holotype, GSC 91700; paratypes, GSC 91701, GSC 91702, and GSC 91703 (Pl. 2.8, figs. 1-11, 14, 15).

Type locality and type stratum. Toad River Bridge section (Norford et al., 1967, p. 515-519), GSC loc. 64550, 124.5 to 134 m above base. Nonda Formation. Lower Silurian (Llandovery).

Diagnosis. Medium-sized shells of *Hercotrema*. Septalium poorly formed, supported by low median septum.

Description. Shell small to medium-sized, subpentagonal to subcircular, nearly equibiconvex (Fig. 2.9). Hingeline weakly curved, attaining about one third of shell width. Anterior commissure uniplicate.

Pedicle umbo low, narrow, moderately to strongly convex, noncarinate, with suberect beak. Delthyrium open, with permesothyridid foramen. Sulcus relatively narrow, deep, beginning 6 to 7 mm from apex; bearing three simple, fine, subrounded costae. Brachial umbo moderately convex, with beak buried in umbonal cavity of pedicle valve. Fold rising from umbonal median furrow 5 mm anterior of hingeline, with four costae. Each shell flank with nine to ten fine, simple, subrounded costae. Concentric growth lines not well preserved in silicified specimens.

Dental plates well developed, posteriorly fused to lateral shell wall, anteriorly becoming free to form small dental cavities (Pl. 2.8, figs. 10, 11). Muscle field not well delimited. Septalium poorly formed or absent. Hinge plates narrow. Cardinal process absent. Median septum reduced to low ridge. Crura long, radulifer, strongly curved, anteriorly flattened (Pl. 2.8, fig. 15).

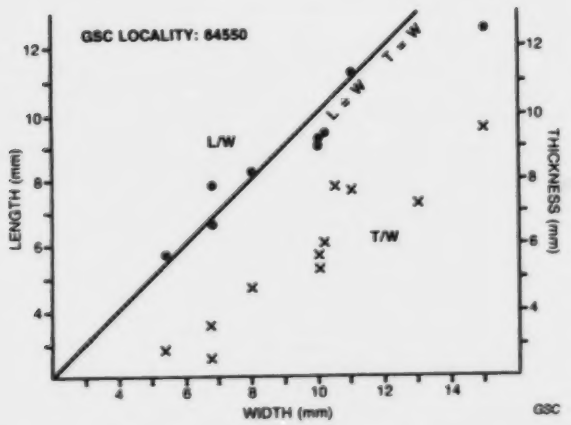

Figure 2.9. *Shell dimensions of* ***Hercotrema humiliseptatum*** *n. sp. The sample is from the Nonda Formation (124.5-134 m above the base) at a section near Toad River bridge (GSC loc. 64550).*

Remarks. Hercotrema humiliseptatum differs from the Upper Silurian species from Bohemia, *H. daphne*, *H. nympha*, *H. infelix*, and *H. incohans* (see Havlíček, 1961), in its nearly equibiconvex shell, narrow fold and sulcus, poorly formed septalium, and low median septum. Like these Bohemian species, *H. pahranagatensis*, *H. borealis*, *H. berryi*, and *H. perryi* have a septalium restricted by marginal cover plates. *Hercotrema humiliseptatum* is similar to the Upper Llandovery *H. bulbicostatum* from Anticosti Island in its tiny septalium without restricted opening. *Hercotrema bulbicostatum*, however, has two anteriorly inflated costae on the fold and a relatively high and thick median septum (Jin, 1989).

Collections. Nonda Formation (total 58 specimens) GSC loc. 45520 (26 disarticulated and silicified valves), Hoole Creek section, 106 m above base of formation; GSC loc. 64550 (32 shells and valves), section near Toad River Bridge, 124.5 to 134 m above base of formation.

Hercotrema winiskensis (Whiteaves, 1906)

Plate 2.8, figures 12-13, 16-23; Figure 2.10

1906 *Camarotoechia*(?) *Winiskensis* Whiteaves, p. 272, Pl. 25, figs. 5-6.
1956 *Camarotoechia winiskensis* Whiteaves; Stearn, p. 104, Pl. 11, fig. 7.
1966 *Stegerhynchus*(?) *winiskensis* (Whiteaves); Bolton, p. 42, Pl. 18, figs. 6, 13 (two syntypes illustrated).
1972 *Stegerhynchus*(?) *winiskensis* (Whiteaves); Bolton and Copeland, p. 24, Pl. 1, figs. 14, 16, 19-28.
1974 *Decoropugnax* aff. *winiskensis* (Stearn) *non* (Whiteaves), Lenz, p. 1130, Pl. 2, figs. 1-12, 15, 20.
1984 *Ancillotoechia winiskensis* (Whiteaves); Larsson, p. 110, Pl. 8, figs. 14-19. (Larsson's collections are re-examined herein.)

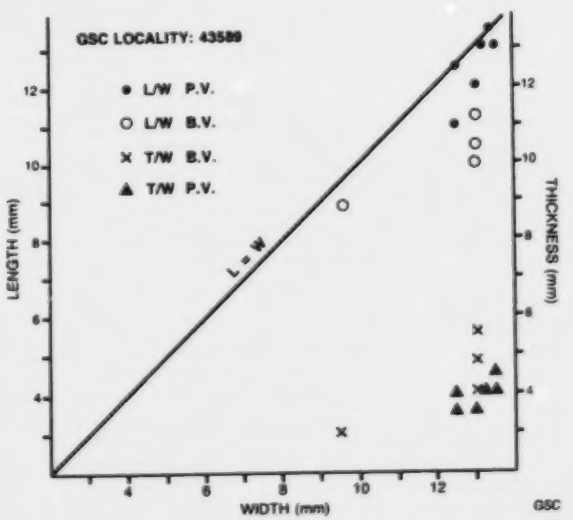

Figure 2.10. *Shell dimensions of* ***Hercotrema winiskensis*** *(Whiteaves, 1906). The sample is from the Nonda Formation at a section near Lapie Lake. Note that the brachial valves are generally deeper than the pedicle valves.*

Type specimens. Two syntypes: GSC 4198 and GSC 4198a (illustrated in Bolton, 1966). Specimen GSC 4198 is slightly compressed, but complete, and is selected herein as the lectotype.

Type locality and type stratum. Winisk River (about 54°56'N, 85°30'W), northern Ontario. Severn River Formation (Middle Llandovery).

Description. (Based on Rocky Mountains collections.) Shell medium-sized, subpentagonal to subcircular, unequally biconvex, with deeper brachial valve (Fig. 2.10). Hingeline short. Anterior commissure finely denticulate, uniplicate.

Pedicle umbo relatively high, slightly tapering, uniformly convex, and with suberect to erect beak. Delthyrium open. Sulcus shallow, broad, becoming clearly defined only near anterior margin, bearing six to seven fine, simple costae. Brachial umbo slightly more convex than pedicle umbo. Fold low, rising above shell contour only near anterior margin, and with six fine costae.

Dental plates relatively thin, high, supporting small teeth. Muscle field not well impressed. Septalium poorly formed or absent. Hinge plates narrow, in most specimens attached directly to shell floor. Cardinal process absent. Median septum absent or reduced to a low ridge. Crura radulifer.

Remarks. Hercotrema winiskensis differs from *H. humiliseptatum* in its fine and numerous costae, broad fold and sulcus, and reduced median septum. *Hercotrema winiskensis* does not belong to *Ancillotoechia* (see Larsson, 1984) because it lacks a complete septalial coverplate. Its designation as *Decoropugnax* by Lenz (1974) cannot be justified, as *Decoropugnax* is characterized by posteriorly smooth shells (Havlicek, 1961).

Collections. (Total of 140 specimens), Nonda Formation, GSC loc. 43589 (12 disarticulated valves), near Lapie Lake; GSC loc. 45521 (8 immature specimens), Hoole Creek section, 39 m above base; GSC loc. 45523 (11), Hoole Creek section, 288 m above base; GSC loc. 45568 (14 valves), Mile 474, Alaska Highway; GSC loc. 46519 (7), Gathto Creek section, 130 m above base; GSC loc. 64546 (80), Toad River Bridge section, 194 to 203 m above base; GSC loc. 46548 (5 specimens), Toad River bridge section, 148 to 153 m above base. Beaverfoot Formation, GSC loc. 52170 (3 specimens), section 1.5 km north of Hatch Creek, 257 m from base of formation.

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PLATE 2.1

Figures 1-4. *Rhynchotrema* sp.

GSC 91670, brachial, ventral, lateral and posterior views, silicified shell from a ridge between the first and second creek north of Brisco (GSC loc. 8060). Beaverfoot Formation (stratigraphic position uncertain), x3.

Figures 5-26. *Hypsiptycha occidens* (Wilson, 1926)

5-9. GSC 6746, lectotype, intensely silicified shell with few growth lamellae preserved. Note the medially conjunct deltidial plates. GSC loc. 7081, Stoddart Creek section. Beaverfoot Formation, x3.

10-18. GSC 6745a-b, paralectotype valves of a single shell. The growth lamellae are well preserved only in the pedicle valve. GSC loc. 7563, about 1 km east of Palliser Pass. Beaverfoot Formation, x3 (fig. 14, pedicle valve with growth lamellae, x6; fig. 16, damaged cardinal process, x9; fig. 18, dental plates, x7.5).

19-21. GSC 6747, paralectotype, specimen previously assigned to *Rhynchotrema pisina* Wilson, 1926, GSC loc. 7800, Stoddart Creek section, Beaverfoot Formation, x4.

22-26. GSC 91671, hypotype, GSC loc. 7628, about 350 m east of Palliser Pass, Beaverfoot Formation, x4.

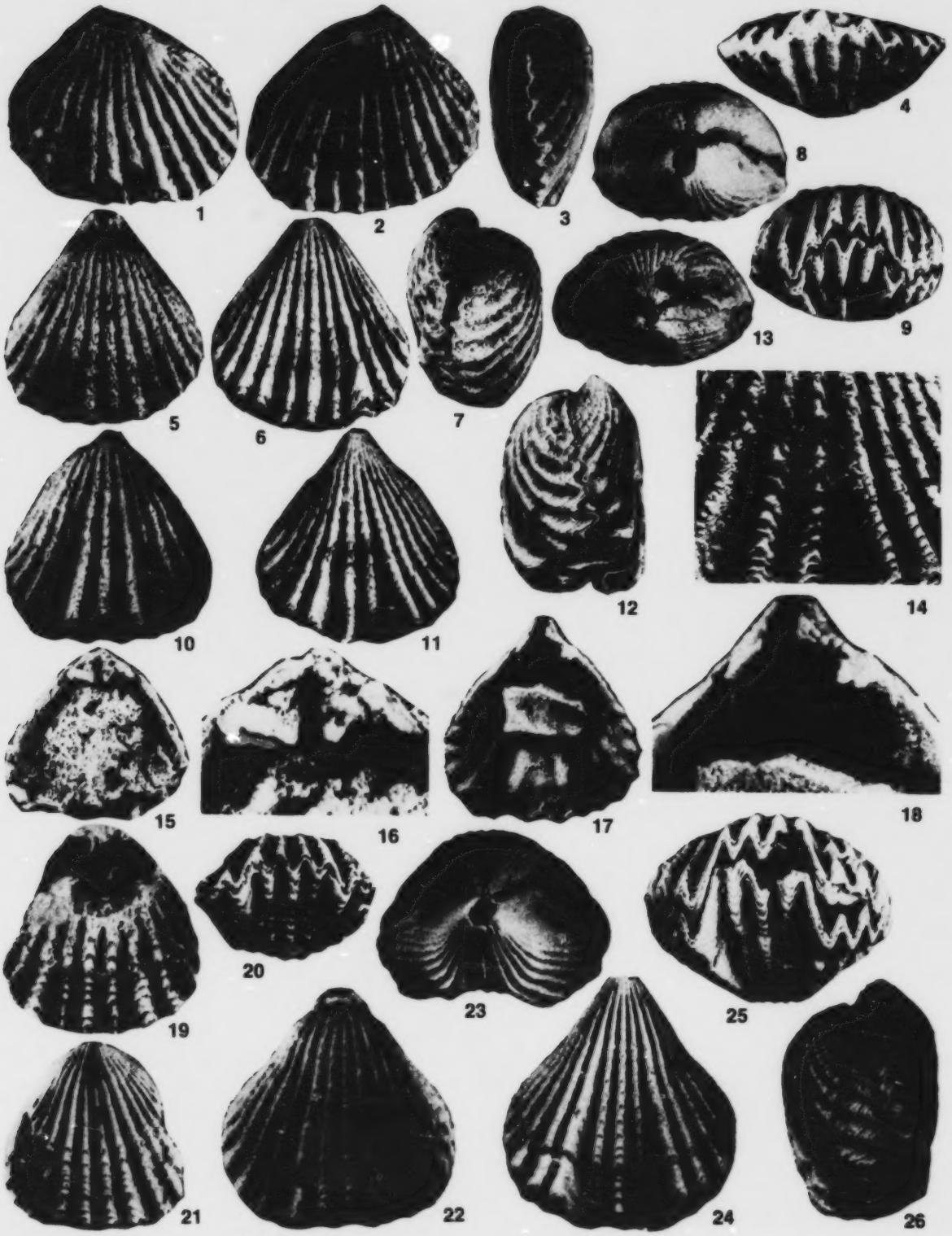
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PLATE 2.2

Figures 1-10. *Hypsiptycha occidens* (Wilson, 1926)

1-3, 9-10. GSC 91672, hypotype. Note the medially conjunct deltidial plates and mesothyridid foramen (figs. 1, 2). The radulifer type of crura are distally ornamented (figs. 9, 10). GSC loc. 7628, about 350 m east of Palliser Pass. Beaverfoot Formation (fig. 1, x3; fig. 2, x9; figs. 9, 10, x7).

4. GSC 91673, hypotype, brachial valve showing a cardinal process and crura. GSC loc. 7969, western slope of 2560 m knoll near Mount Sir Douglas. Beaverfoot Formation, x4.

5, 6. GSC 91674, hypotype, brachial valve showing a cardinal process, median septum, and crura. GSC loc. 7969, x5, fig. 6, x10.

7. GSC 91675, hypotype, pedicle valve showing dental plates and muscle field. GSC loc. 7969, x8.

8. GSC 91676, hypotype, pedicle valve with dental plates. Note that the muscle field is much smaller than that in fig. 7. GSC loc. 7969, x7.

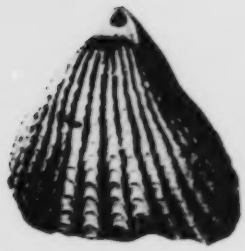
Figures 11-14. *Hypsiptycha neenah* (Whitfield, 1882)

GSC 91677, hypotype, brachial valve from the section, 1.5 km north of Hatch Creek (GSC loc. 8041). Note the weakening of flanking costae on fold near anterior margin (fig. 12) and the development of grooves on lateral costae (fig. 14, x10). Beaverfoot Formation (25.4 m above base), x5.

Figures 15, 16. *Hiscobeccus windermeris* (Wilson, 1926)

15. GSC 91679, hypotype, pedicle valve. GSC loc. 7801, Stoddart Creek section. Beaverfoot Formation, x2.

16. GSC 91678, hypotype, interior of silicified brachial valve showing septiform cardinal process. GSC loc. 45612, Mount Sinclair section. Beaverfoot Formation, x10.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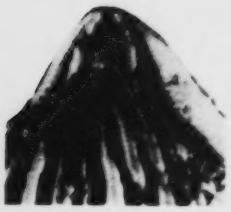
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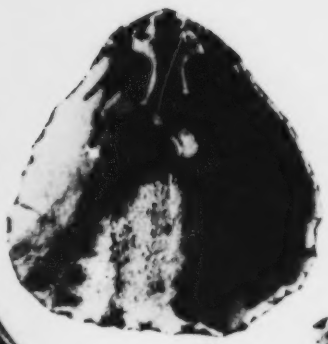
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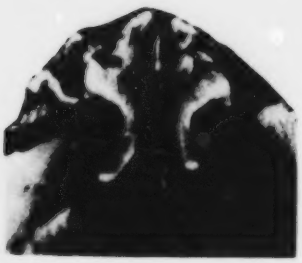
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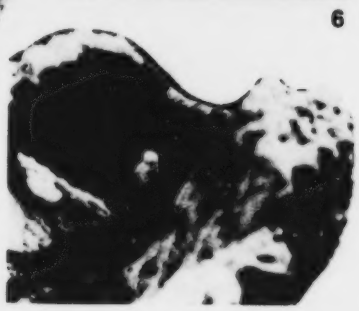
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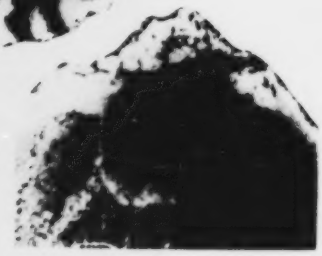
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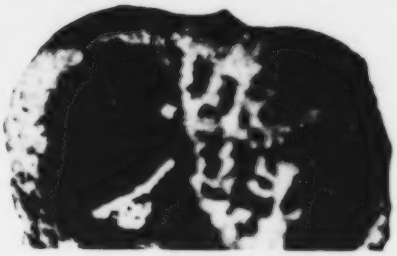
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PLATE 2.3

Figures 1-16. *Hiscobeccus kananaskia* (Wilson, 1926)

1-5. GSC 6749, lectotype. The growth lamellae are obscured by silicification. Note the erect beak and lack of deltidial plates. GSC loc. 7628, 350 m east of Palliser Pass. Beaverfoot Formation, x3.

6-9. GSC 6749a, paralectotype, partly damaged specimen with well preserved growth lamellae and an incurved beak. GSC loc. 7628, x3.

10-14. GSC 91680, hypotype, intensely silicified and recrystallized shell, with obscure growth lamellae. GSC loc. 8042, section 1.5 km north of Hatch Creek. Beaverfoot Formation (20 m above base), x3.

15. GSC 6749b, paralectotype, broken shell with strong growth lamellae in the pedicle valve. GSC loc. 7628, x3.

16. GSC 91681, hypotype, brachial valve showing a cardinal process and median septum. GSC loc. 52159, section near Akutlak Creek. Beaverfoot Formation (118 m above base), x3.

Figure 17. *Hiscobeccus windermeris* (Wilson, 1926)

GSC 91678 (same specimen as Pl. 2.2, fig. 16) showing growth lamellae, x3.

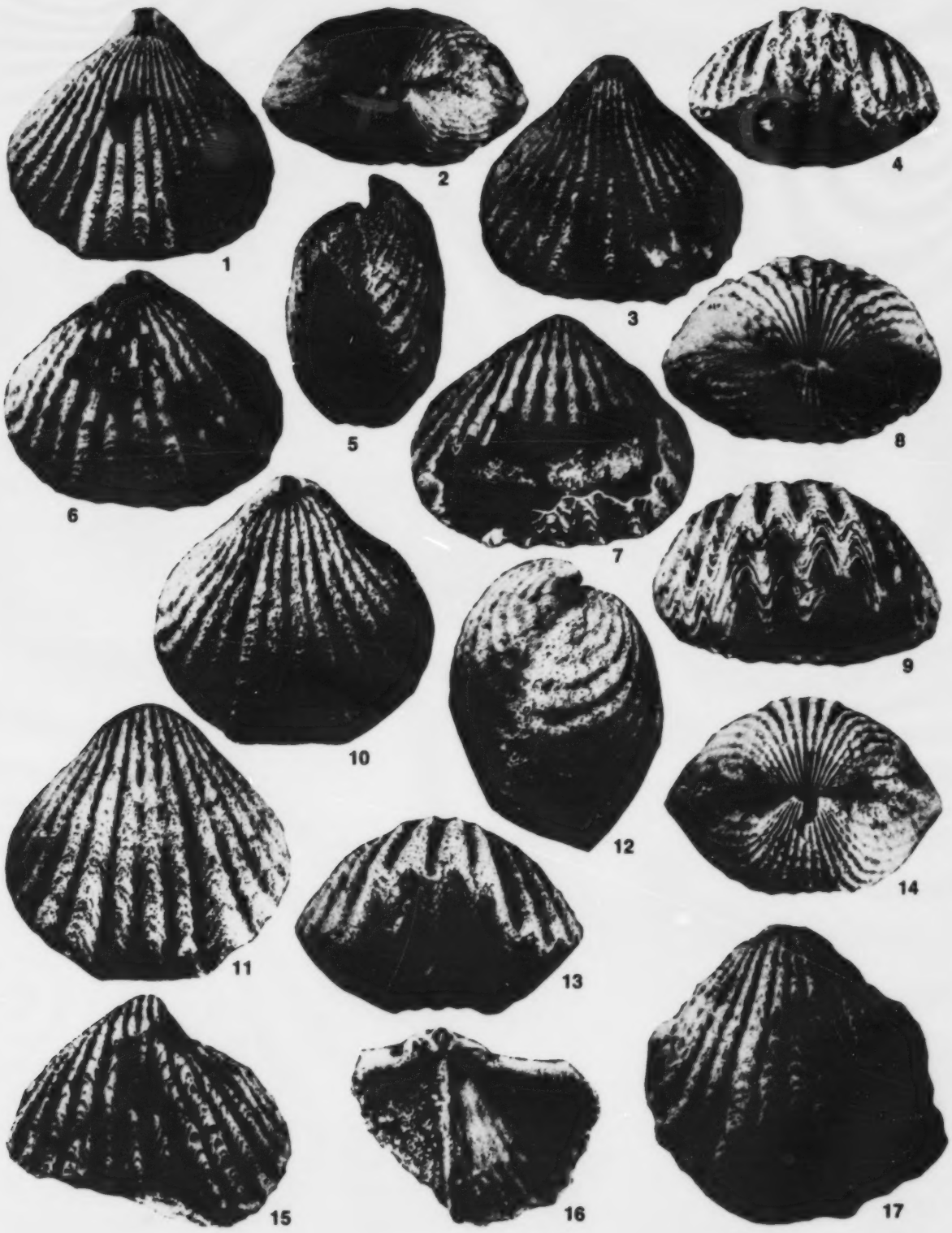
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PLATE 2.4

Figures 1-14. *Lepidocyclus erectus* Wang, 1949

1-6. GSC 91683, hypotype, silicified shell with well preserved growth lamellae and medially conjunct deltidial plates. GSC loc. C-137719, isolated outcrop, NTS 82J 633200E, 5550250N. Lower Beaverfoot Formation, x3 (fig. 3, x7.5).

7-11. GSC 91684, hypotype, slightly compressed specimen from GSC loc. 45548, Wonah Ridge section, Mount Sinclair. Beaverfoot Formation (10 m above base), x3 (fig. 8, x7.5).

12, 13. GSC 91708, hypotype, brachial valve with large hinge plates and a septiform cardinal process. GSC loc. 42017, Cirrus Mountain section, Alberta. Beaverfoot Formation, x3.5 (fig. 13, x9).

14. GSC 91685, hypotype, shell cross-cut to show the articulatory structures and crura. GSC loc. 45548, x3.5.

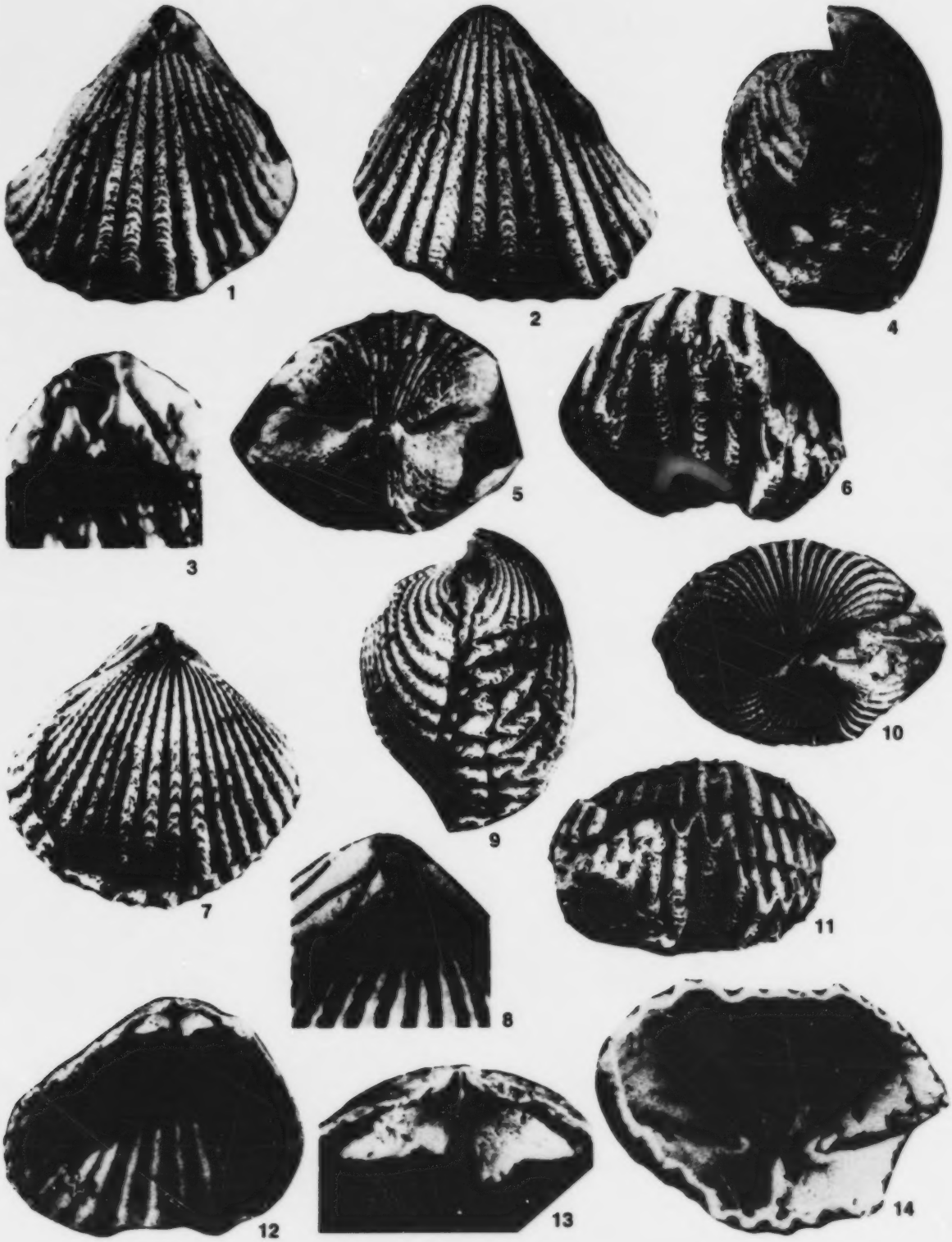
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PLATE 2.5

Figures 1-10. *Stegerhynchus borealis* (von Buch, 1834)

1-5. GSC 91686, hypotype. GSC loc. 64544, Toad River bridge section. Nonda Formation (257 m above base), x4.

6-10. GSSC 91687, hypotype, GSC loc. 64544, x5.

Figures 11-19. *Stegerhynchus praecursor* Foerste, 1909

11-15. GSC 91688, hypotype, small specimen from GSC loc. 45541, Mount Sinclair section. Beaverfoot Formation (348 m above base), x6.

16, 17. GSC 91689, hypotype, brachial valve with a relatively long median septum and a partly broken cardinal process. GSC loc. 47400, Pedley Pass section. Beaverfoot Formation (363 m above base), x6.

18-19. GSC 91690, hypotype, pedicle valve with no dental plates preserved. Note the small, shallow muscle field. GSC loc. 23859, peak near Moscow Creek. Upper Beaverfoot Formation, x5.

Figures 20-24. *Stegerhynchus concinna* (Savage, 1913)

GSC 91691, hypotype, intensely silicified specimen from the Gathto Creek section (GSC loc. 64516), Nonda Formation (188 m above base), x4.

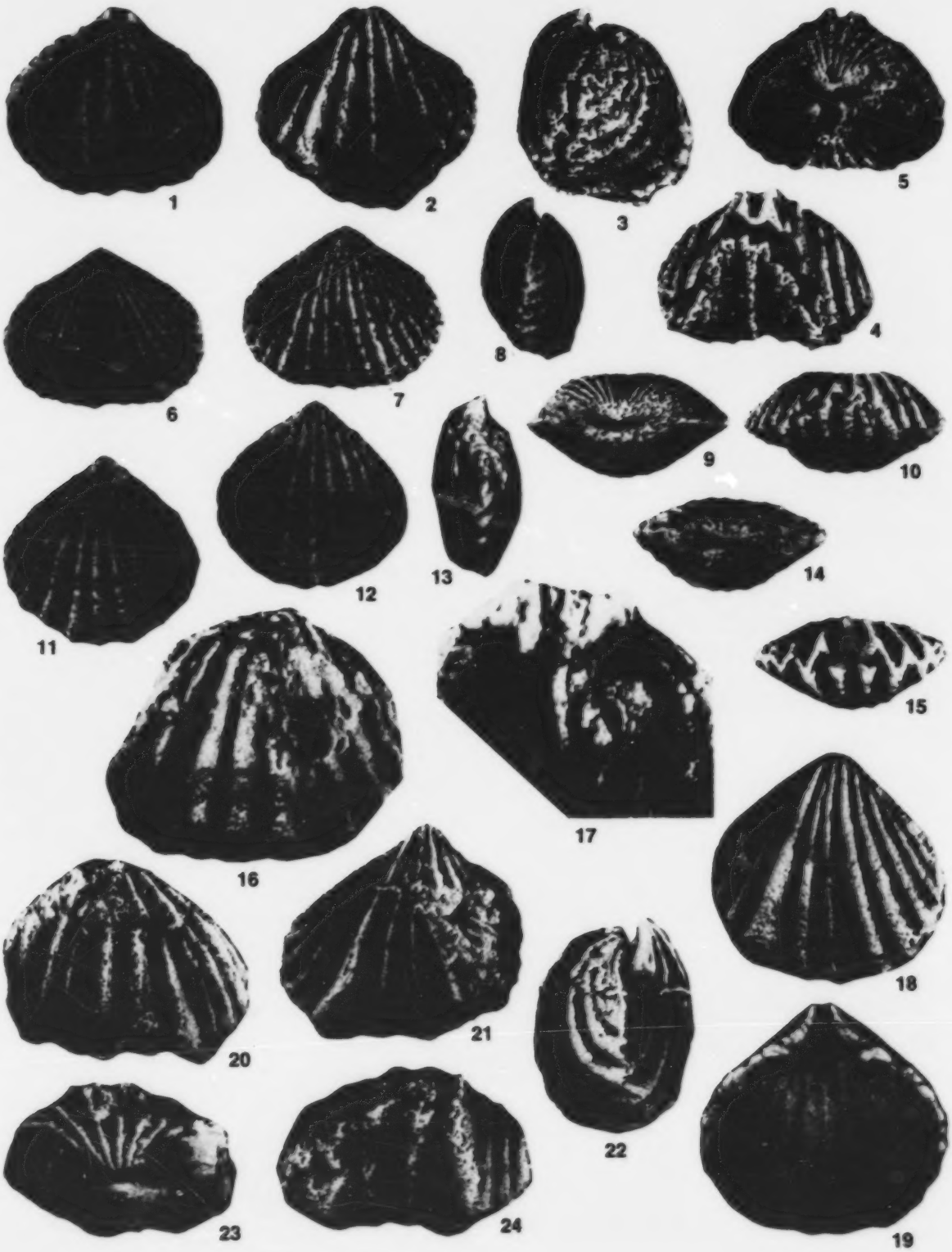
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PLATE 2.6

Figures 1-5. *Stegerhynchus peneborealis* (Twenhofel, 1928)

GSC 91692, hypotype. GSC loc. C-137715, isolated outcrop north of Mount Harrison, NTS 82 J, 633800E, 5552700N. Upper Beaverfoot Formation, x3.

Figures 6-16. *Gnamptorhynchos inversum* Jin, 1989

6-11. GSC 91693, hypotype. Dorsal, ventral, posterior, anterior, and lateral views of a silicified and recrystallized shell. Note the well preserved interarea in the pedicle valve. GSC loc. C-147466, north flank of Russell Peak, isolated outcrop, NTS 82 J, 624900E, 5589600. Beaverfoot Formation (basal 5 m), x3.5 (fig. 11, x8).

12-14. GSC 91694, hypotype, brachial valve showing crural bases, hinge sockets, and accessory sockets. GSC loc. 32302, Fernie map area, isolated outcrop, lat. 49°50'38"N, long. 115°26'46"W. Beaverfoot Formation, x3 (fig. 14 shows the septalium with a low lobe of the cardinal process, x8).

15, 16. GSC 91695, hypotype, pedicle valve showing a muscle field enclosed by dental plates. Note the intercalation of costae (fig. 15). GSC loc. 7969, near Mount Sir Douglas. Beaverfoot Formation, x4.

Figures 17-24. *Rostricellula pisina* (Wilson, 1926)

17-21. GSC 6747a, lectotype, intensely silicified and recrystallized shell from GSC loc. 7800, Stoddart Creek section. Lower Beaverfoot Formation, x5.

22-24. GSC 6748, paralectotype, complete specimen buried in rock matrix. GSC loc. 5064, Carbonate Creek section. Lower Beaverfoot Formation (High in Whiskey Trail Member), x5.

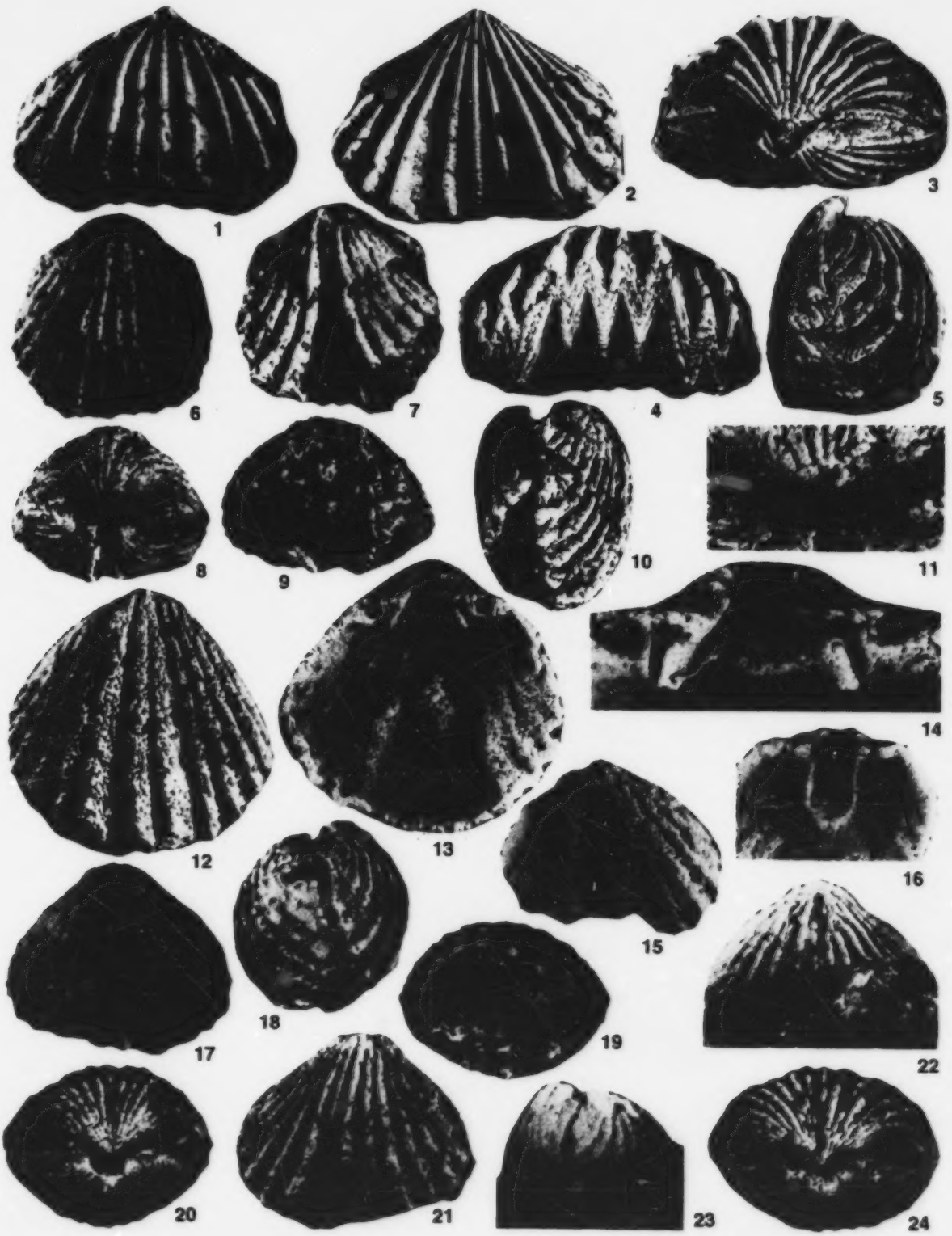
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PLATE 2.7

Figures 1-9. *Rostricellula pisina* (Wilson, 1926)

1-5. GSC 91696, hypotype. GSC loc. 43940, ridge between Bull River and Quinn Creek. Beaverfoot Formation, x4.

6-9. GSC 91697, hypotype. GSC loc. 43940, x4.

Figures 10-19. *Lepidocycloides rudicostatus* n. sp.

10-15. GSC 91698, holotype, calcareous specimen with its anterior shell material peeled. Note the growth lamellae preserved in the lateral posterior part (figs. 14, 15). GSC loc. 8026, near Brisco. Beaverfoot Formation, x2 (fig. 5, x8).

16-19. GSC 91699, paratype, shell with a compressed anterior. GSC loc. 8026, x2.

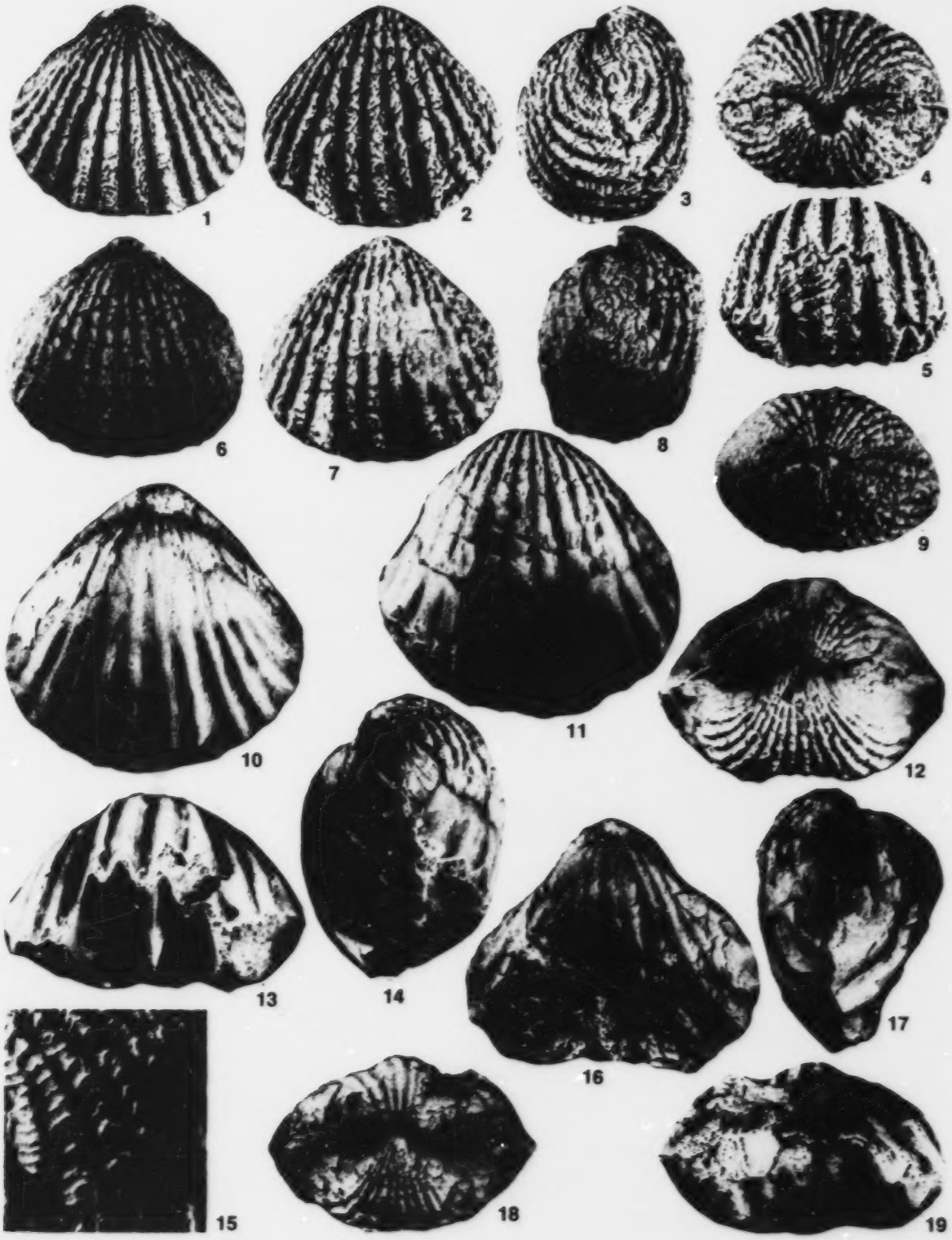
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PLATE 2.8

Figures 1-11, 14, 15. *Hercotrema humiliseptatum* n. sp.

Four specimens from GSC loc. 64550, Toad River bridge section, 3 km northwest of Toad River Bridge on Alaska Highway. Nonda Formation (124.5-134 m above base).

1-4. GSC 91700, holotype, x3.

5-8. GSC 91701, paratype, x3.

9-11. GSC 91702, paratype. Pedicle valve, x4 (fig. 11, x12).

14, 15. GSC 91703, paratype. Brachial valve (fig. 14, x3; fig. 15, x9).

Figures 12, 13, 16-23. *Hercotrema winiskensis* (Whiteaves, 1906)

Four specimens from GSC loc. 45568, section near Mile 474, Alaska Highway. Nonda Formation.

12, 13. GSC 91704, pedicle valve, x4.

16, 17. GSC 91705, brachial valve, x4.

18-20. GSC 91706, pedicle valve, x3 (fig. 20 shows dental plates, x7.5).

21-23. GSC 91707, brachial valve showing relatively small, sessile hinge plates, and low median ridge, x3 (fig. 23, x8).

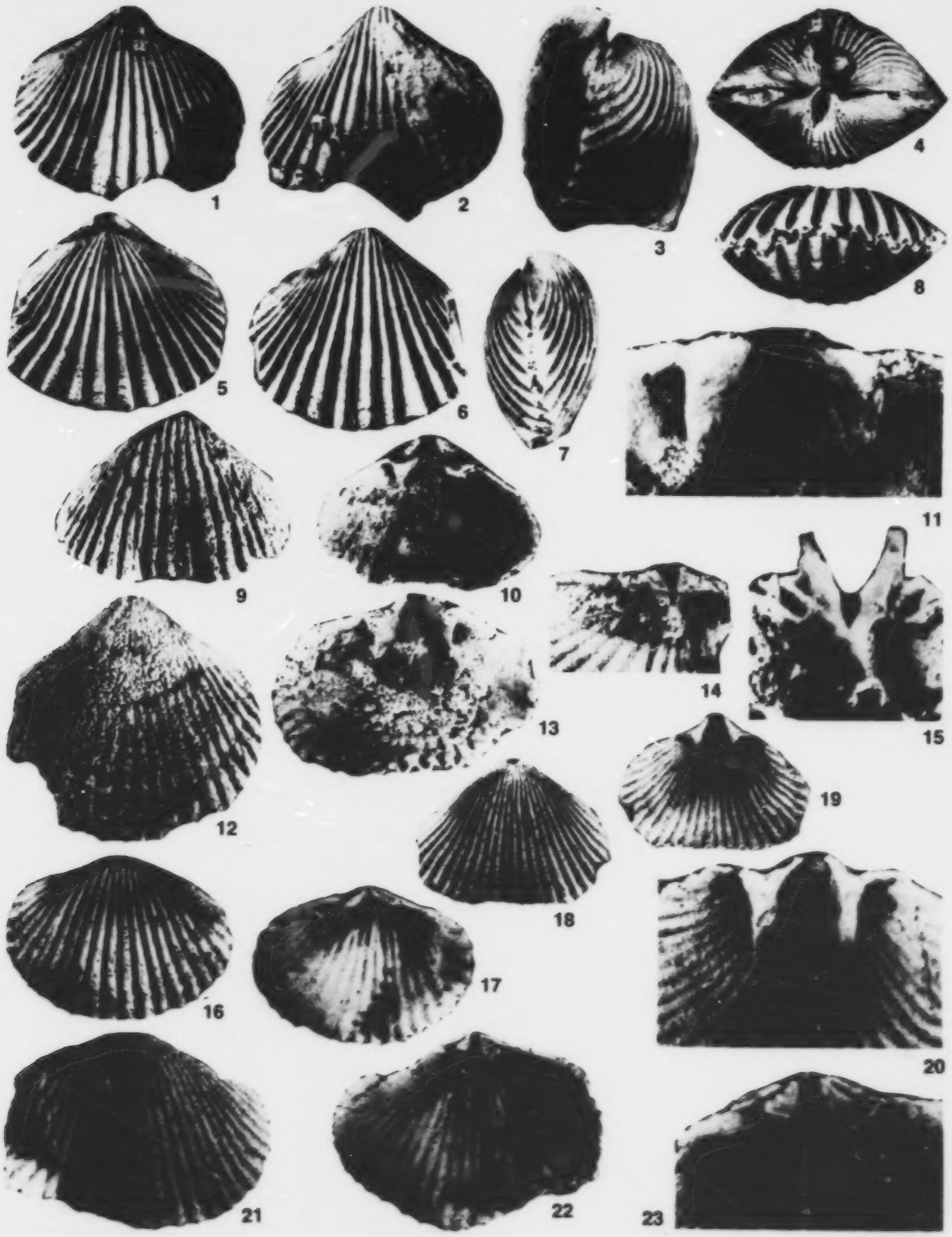
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PLATE 2.9

Figures 1-8. *Hypsiptycha occidens* (Wilson, 1926)

Serial sections of hypotype GSC 91709 (see Figure 2.6).

1, 2. Medially conjunct deltidial plates, 0.6, 0.9 mm from apex, x50.

3. Posterior part of cardinal process, 1.3 mm from apex, x40.

4, 5. Anteriorly inflated part of cardinal process. Note the trilobate crest, 2.0 mm from apex, x35 (fig. 5, x100).

6, 7. Anterior part of crura, 3.8 mm from apex, x50.

8. Median septum, 1.9 mm from apex, x50.

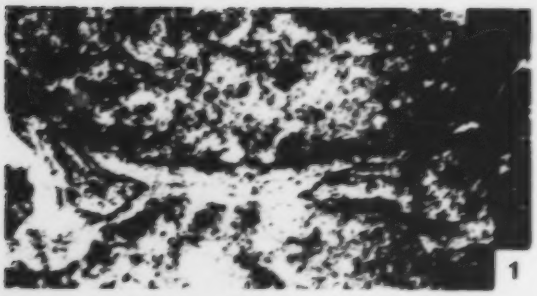
Figures 9-11. *Lepidocycloides rudicostatus* n. sp.

Serial sections of paratype GSC 91710 (see Figure 2.8).

9. Junction of dental plates with shell, 2.2 mm from apex, x50.

10. Median septum, 2.5 mm from apex. Note the lamellar structure, x45.

11. Septalium with its opening restricted by crural bases projecting into septalial cavity, 2.5 mm from apex, x40.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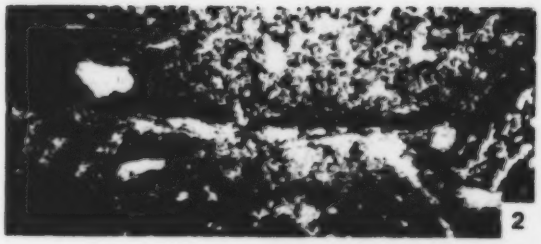
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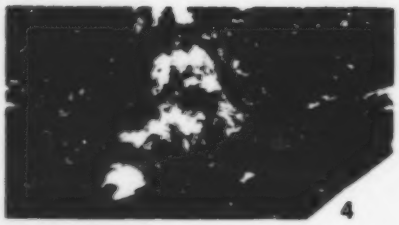
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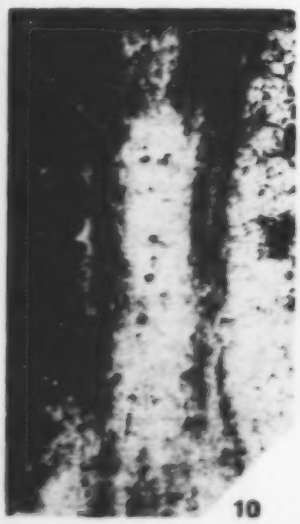
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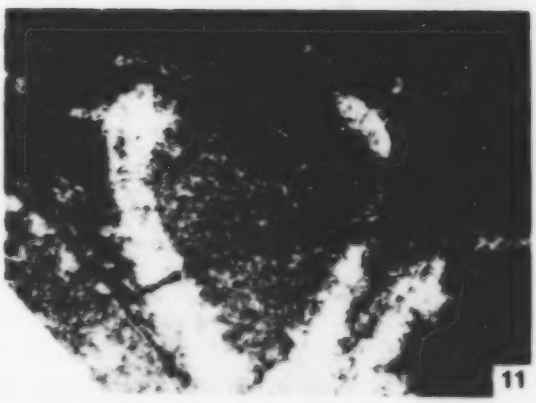
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NEW GENERA OF MIDDLE DEVONIAN RUGOSE CORALS FROM THE TYPE HORN PLATEAU REEF, DISTRICT OF MACKENZIE

A.E.H. Pedder[1]

Pedder, A.E.H., New genera of Middle Devonian rugose corals from the type Horn Plateau Reef, District of Mackenzie. In Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 396, p. 61-87, 1989.

Abstract

Agastophyllum eximium gen. et sp. nov., a massive digonophyllid coral, is described from the reef flat and organic reef macrofacies of Vopni and Lerbekmo (1972). *Dialeptophyllum vopnii* gen. et sp. nov., a solitary kyphophyllid coral, is described from the reef flank macrofacies. *Thryptophyllum undafundus* gen. et sp. nov. is described from the reef flat and reef flank macrofacies, and is referred to a new subfamily of the Cyathophyllidae, named Thryptophyllinae. *Agastophyllum eximium* and *Thryptophyllum undafundus* are Givetian, Middle *varcus* Zone age; *Dialeptophyllum vopnii* is presumed to belong to the same zone, and is certainly Givetian.

Four undescribed species of *Agastophyllum* are reported from late Eifelian strata of Western Canada. *Dialeptophyllum vopnii* and an unnamed Emsian species from the Nelichen Formation of the Indigirka River drainage area of the northeastern Soviet Union are the only known species of *Dialeptophyllum*. An early Givetian species from the Rockport Quarry Limestone of Michigan, originally described by Ehlers and Stumm (1949), under the name *Spongophyllum romingeri*, is transferred to the new genus *Thryptophyllum*.

Résumé

Agastophyllum eximium gen. et sp. nov., corail digonophyllidé massif provenant d'un macrofaciès de platier et de récif organique, est décrit. On décrit également *Dialeptophyllum vopni* gen. et sp. nov., corail kyphophyllidé solitaire du microfaciès de flanc de récif. Enfin, *Thryptophyllum undafundus* gen. et sp. nov. du microfaciès de platier et de flanc de récif est aussi décrit et est rattaché à une nouvelle sous-famille des Cyathophyllidae, appelée Thryptophyllinae. *Agastophyllum eximium* et *Thryptophyllum undafundus* sont d'âge givétien (partie intermédiaire de la zone à *varcus*); *Dialeptophyllum vopnii* proviendrait de la même zone et est certainement d'âge givétien.

Quatre espèces non décrites d'*Agastophyllum* ont été observées dans des couches de l'Eifélien supérieur dans l'Ouest canadien. *Dialeptophyllum vopnii* et une espèce emsienne non désignée de la formation de Nelichen de la zone hydrographique de la rivière Indigirka dans le nord-est de l'Union Soviétique sont les seules espèces connues de *Dialeptophyllum*. Une espèce du Givétien inférieur contenue dans le calcaire de Rockport Quarry du Michigan, d'abord décrit sous le nom de *Spongophyllum romingeri*, est transféré au nouveau genre *Thryptophyllum*.

INTRODUCTION

Collections currently under study from the type Horn Plateau Reef (Givetian) include representatives of 30 or more species of rugose corals. Some of these have been formally described by McLaren (in McLaren and Norris, 1964) and by Pedder (1986); others will be described in forthcoming works. Genera, or subgenera, known to be present in the Horn Plateau coral faunas are: *Cystiphylloides*, *Lythophyllum*, *Microplasma*, *Zonophyllum*, *Lekanophyllum*, *Scissoplasma*, *Siphonophrentis*, *Zelophyllia*, *Neospongophylloides*, *Tabulophyllum*, *Australophyllum* s.l., *Grypophyllum*, *Psydracophyllum* s.l., *Sociophyllum*, *Parasunophyllum*, *Disphyllum*, *Cylindrophyllum*, *Heliophyllum*? (single imperfect specimen), *Cyathophyllum*, *Minussiella*, *Peripaedium*, and four new genera.

Three of these new genera have easily definable morphological limits and unequivocal familial relationships. They are named *Agastophyllum*, *Dialeptophyllum* and *Thryptophyllum* in the present paper. The fourth new genus is based on a highly variable type species, and is defined to some extent by its phylogenetic relationships. It is described under the name *Rhytidolasma* in a companion paper (Pedder, this volume).

GEOLOGICAL SETTING

The type Horn Plateau Reef is one of at least ten small reefs in southwestern District of Mackenzie and northeastern British Columbia that grew on a regionally extensive upper Eifelian limestone platform consisting of, depending on the area, the Horn Plateau, Nahanni, or Hume formations. As the North American Plate is presently positioned, these reefs lie north and east of the Devonian Tathlina Arch and Keg River barrier reef complex. Most of the reefs are covered by younger sediments, but the type Horn Plateau Reef, near Fawn Lake (Fig. 3.1), and another, near the confluence of Landry Creek and Root River (lat. 62°56.5'N; long. 125°14'W), are exposed.

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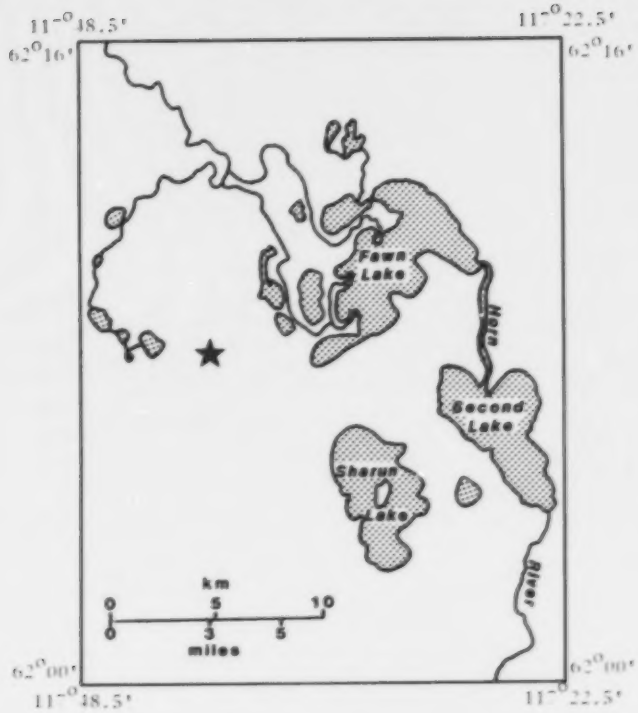

Figure 3.1. *Map of the Fawn Lake area, southwestern District of Mackenzie, with location of the type Horn Plateau Reef indicated by a star.*

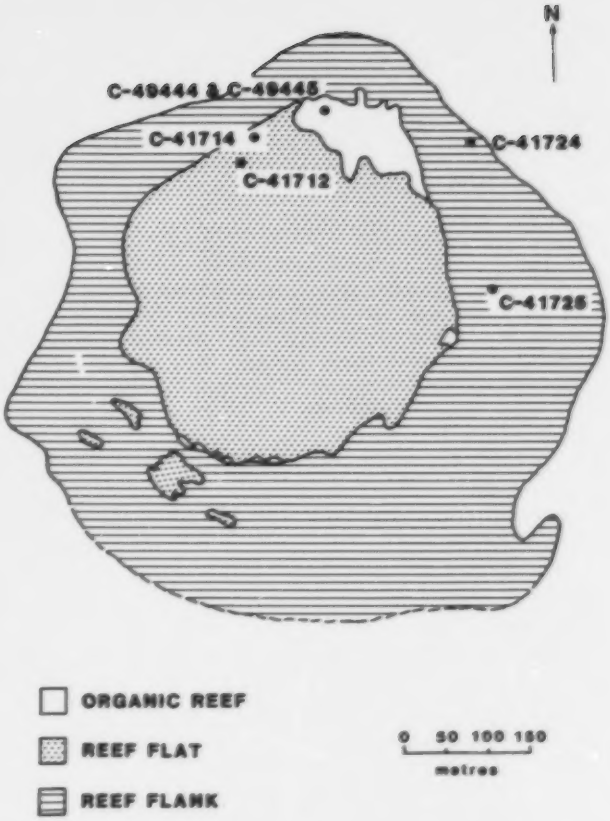

Figure 3.2. *Plan of macrofacies over the present surface of the type Horn Plateau Reef (after Vopni and Lerbekmo, 1972a, Fig. 6; 1972b, Fig. 6).* ***Agastophyllum eximium*** *Pedder occurs at GSC localities C-41714, C-49444 and C-49445;* ***Dialeptophyllum vopnii*** *occurs at GSC locality C-41724;* ***Thryptophyllum undafundus*** *Pedder occurs at GSC localities C-41712 and C-41725.*

The physical stratigraphy of the reef near Fawn Lake has been described by Fuller and Pollock (1972, p. 147-150) and by Vopni and Lerbekmo (1972a, b). The three macrofacies recognized by Vopni over the present surface exposure of the reef are shown in Figure 3.2. *Agastophyllum eximium* sp. nov. occurs in the reef flat macrofacies at locality C-41714 and in the organic reef macrofacies at localities C-49444 and C-49445. *Dialeptophyllum vopnii* sp. nov. has been found only in the reef flank macrofacies at locality C-41724. *Thryptophyllum undafundus* sp. nov. occurs abundantly in the reef flat macrofacies at locality C-41712, and one specimen has been collected from the reef flank macrofacies at locality C-41725.

The age of the fauna, including *Agastophyllum eximium*, from the exposed organic reef macrofacies has been deduced previously as Givetian, Middle *varcus* Zone (Pedder, 1986, p. 472). The presence of *Polygnathus angustus* and *P. xylus ensensis* in beds of the reef flat macrofacies that yield *Thryptophyllum undafundus*, indicates the same Middle *varcus* Zone age. The age of the reef flank fauna with *Dialeptophyllum vopnii* is less closely defined, but is certainly Givetian, and is probably also Middle *varcus* Zone age.

SYSTEMATIC PALEONTOLOGY

Phylum COELENTERATA Frey and Leuckart, 1847

Class ANTHOZOA Ehrenberg, 1834

Order CYSTIPHYLLIDA Nicholson, 1889

Family CYSTIPHYLLIDAE Milne Edwards and Haime, 1850

Discussion. Birenheide (1964, 1978), McLean (1976, 1977) and Hill (1981), who have published opinions influencing studies of Canadian Devonian cystimorph corals, disagreed on how such corals should be classified. Birenheide (1964) combined all of the Devonian cystimorph corals under the family Cystiphyllidae, but divided them, on the presence or absence of an operculum, into the subfamilies Goniophyllinae and Plasmophyllinae. The essentials of this scheme were retained in Birenheide's 1978 work. However, because by that time it was known that the name *Plasmophyllum* should be used only for lykophyllid corals (Weyer, 1971), the subfamily name Plasmophyllinae was replaced by the Digonophyllinae. McLean (1976, 1977) excluded operculate corals from the Cystiphyllidae, but included various Silurian genera, such as *Holmophyllum*, that were assigned to the Holmophyllidae by Hill (1981). McLean recognized two subfamilies within the Cystiphyllidae based on the absence of continuous, radial septal crests in the Cystiphyllinae and the presence of such structures in the Digonophyllinae. Unlike Birenheide and McLean, Hill (1981) elevated the Digonophyllinae to full family rank.

The distinction between the Cystiphyllidae and Goniophyllidae is clear cut, and is much greater than that between the Cystiphyllidae and Digonophyllidae. Indeed, several species, including the one from the Horn Plateau Reef named *Cystiphylloides spinosum* by McLaren (in McLaren and Norris, 1964), are sufficiently variable to lie astride the morphological boundary delimiting the cystiphyllids from the digonophyllids. For this reason, McLean's 1976 and 1977 family classification is adhered to in this work, although the number of cystiphyllid genera recognized by the present author is greater than that recognized by McLean in 1976. Two genera now held to be valid are *Lythophyllum*, which has been discussed in detail recently (Pedder, 1985, p. 291-293), and *Scissoplasma*. *Scissoplasma* is based on a Horn Plateau species, and is much better known now than either when it was proposed, or when it was considered by McLean.

Subfamily DIGONOPHYLLINAE Wedekind, 1923

Genus *Agastophyllum* gen. nov.

Type species. *Agastophyllum eximium* sp. nov.

Diagnosis. Predominantly massive, pseudocerioid to plocoid genus of cystimorph corals. Increase nonparricidal and marginarial. Major septa radially disposed, comprising well developed lamellae in the inner region of the dissepimentarium. Minor septa variable, but on the whole weak. Septal crusts typically thin, locally entirely absent. Trabeculae fine (diameter <0.13 mm), preserved as holacanths in available material. Dissepiments and presepiments relatively small and abundant. Tabulae vesicular, forming concave tabularial surfaces.

Discussion. Individual corallites of *Agastophyllum* are normally prismatic, but in other respects resemble the entire corallum of a specimen of *Lekanophyllum* Wedekind (1924, p. 29-34) (see Pedder and McLean, 1982, p. 75 for synonymous genera). They also resemble individual corallites of *Scissoplasma* Spasskiy and Kravtsov (in Spasskiy et al., 1975, p. 171), which is recognized now as a valid genus. The massive corallum of the new genus differentiates it from the other two genera. *Lekanophyllum* is a solitary genus; *Scissoplasma* is fasciculate, generally phaceloid, so that its corallites are more or less cylindrical. *Mackenziephyllum* Pedder (1971, p. 48) and the synonymous cystiphyllid genera *Zonastraea* Tsyganko (1972, p. 21-22), *Subutaratuia* Yu and Cao (1983, p. 19, 66-67) and *Sigelophyllum* Cao in Yu and Cao (1983, p. 20-21) have massive coralla like *Agastophyllum*, but their septal skeleton is restricted to short, cone-like spines.

None of the many previously described cystimorph corals is referred to the new genus, although as many as four undescribed species are known to the author from the upper Eifelian faunas of Western Canada. The diagnosis prepared for *Agastophyllum* takes into account the morphologies of these unnamed species.

Etymology. From the Greek words, *agastos*, meaning admirable, and *phyllon*, a leaf.

Agastophyllum eximium sp. nov.

Plates 3.1-3.4

Type series. Holotype, GSC 91283, and two paratypes, GSC 91285, 91286, from GSC locality C-49444. One paratype, GSC 91284, from GSC locality C-49445. One paratype, GSC 91287, from GSC locality C-41714. Eighteen thin sections have been prepared from the type series.

Diagnosis. Large species of *Agastophyllum* with adult corallites having mean diameters of 30 to 50 mm, and 33 to 43 finely carinate major septa. Minor septa mostly spinose rather than lamellar. Trabeculae delicate (diameter 0.05-0.08 mm) but long, commonly penetrating ten or more dissepimentarial layers. Intercorallite wall discontinuous, thickened in places by sclerenchyme that may, or may not, be continuous with septal crusts.

Description. Four of the five type specimens are entirely massive, pseudocerioid to plocoid; the fifth specimen (GSC 91286) is similar, except for a few young subcylindrical corallites at the margin of the corallum, which are not entirely attached to the massive part of the corallum. The largest coralla at the type outcrop of the Horn Plateau Formation are about 230 mm in diameter, 100 mm high, and comprise between 20 and 30 corallites. Increase is nonparricidal and marginarial; new corallites start close to the margin of the parent coral. Lamellar septa appear in the daughter corallite as it enlarges to a diameter of about 7 mm. New corallites develop slowly, so that after 30 mm of vertical growth their diameter is only about 15 mm. The mean diameter of adult corallites varies from 30 to 50 mm, although few are more than 40 mm in mean diameter. The calice approximates the shape of an inverted cone. In young corallites, it is usually as deep as it is wide; in adult corallites, its depth is normally about one half of its width.

Fine structure is not preserved in the type material. Nevertheless, it is clear, especially from longitudinal sections of the holotype, that the discontinuous intercorallite walls consist of septal skeleton reinforced by sclerenchyme. At certain levels, the sclerenchyme continues adaxially over dissepimentarial and tabularial surfaces to form thin septal crusts. Septa are radially arranged and well differentiated into two orders. They are made of thin spines, having diameters of 0.05 to 0.08 mm, which are long, and commonly penetrate ten or more layers of dissepiments. No original structure is preserved in these spines; it is probably safe to assume that they were fine monacanthate trabeculae. In the outer dissepimentarium, septal spines tend to be solitary, but may be grouped to form fragments of septal skeleton, and in places, form rare, discrete carinae of the kind that occur in *Mesophyllum*. In the region of the inner dissepimentarium and outermost tabularium, first order septal spines are united as septal crests to form lamellar septa. However, they are imperfectly aligned, so that fine, irregularly zigzag carinae are also developed. Much shorter and less abundant, solitary spines occur in the tabularium, especially on the thin septal crusts, where they are commonly very short and conical. Minor septa may comprise discontinuous lamellae, but many are represented only by separated spines. They are generally best developed near the periphery of the corallite, but are absent entirely between some major septa. There are 22 to 24 major septa in corallites that have mean diameters of 14 to 20 mm. The number of major septa increases to about 32 in corallites of 30 mm mean diameter. In adult stages, when the mean diameter of the corallite is 30 to 50 mm, the number of major septa varies from 33 to 43.

As in many cystimorph corals, the presepiments and dissepiments do not differ much from the small, incomplete, vesicular tabulae. Large adult corallites generally have about 20 rows of dissepiments and presepiments, and each tabularial surface is supported by a similar number of tabulae. Between the lamellar parts of major septa, most dissepiments do not bridge the interseptal loculus; a few are full lateral dissepiments. Thin sclerenchyme usually thickens the adaxial parts of the major septa. In places, this sclerenchyme passes onto a dissepimentarial surface to form a thin crust.

Remarks. *Agastophyllum eximium* is larger and has more septa than any of the undescribed upper Eifelian species of the genus known from Western Canada. It also has less discontinuous intercorallite walls.

Etymology. The trivial name is the Latin adjective *eximius, -a, -um*, meaning uncommon – the species is known only from the type Horn Plateau outcrop.

Order STAURIIDA Verrill, 1865

Family KYPHOPHYLLIDAE Wedekind, 1927

Subfamily KAKISAPHYLLINAE McLean and Pedder, 1984

Remarks. McLean and Pedder (1984, p. 30-31) proposed this family for *Kakisaphyllum larus*, an upper Frasnian coral from Western Canada, which differs from all other kyphophyllinid corals then known, by having distinctly concave tabularial surfaces. Upper Givetian or lower to middle Frasnian species that might be referred to the Kakisaphyllinae have not been described from either Western Canada or elsewhere. It is possible that *Kakisaphyllum* and the new middle Givetian genus, *Dialeptophyllum*, evolved independently from different kyphophyllid ancestors. But there is no proof of this, and at present, *Dialeptophyllum* is referred to the Kakisaphyllinae without reservation.

Genus *Dialeptophyllum* gen. nov.

Type species. *Dialeptophyllum vopnii* sp. nov.

Diagnosis. Solitary genus of kyphophyllinid coral with sagging tabulae, short major septa and large presepiments.

Discussion. The new genus is distinguished from *Kakisaphyllum* McLean and Pedder (1984, p. 31) by its solitary, rather than fasciculate, form and by its shorter major septa. It is distinguished from *Tabulophyllum* Fenton and Fenton (1924, p. 30-31) and synonymous genera *Apolythophyllum* Walther (1928, p. 135-138), *Sinospongophyllum* Yoh (1937, p. 56) and *Diversophyllum* Sloss (1939, p. 65-66) by its moderately to deeply depressed tabularial surfaces. Also, the prominent rejuvenescences in the dissepimentarium of *Dialeptophyllum vopnii* have no affect on the tabularium, whereas in *Tabulophyllum*, major septa are commonly lengthened over tabularial surfaces following rejuvenescences of similar or less magnitude (Watkins, 1959, Pl. 33, fig. 11; Hill, 1981, fig. 141, 2b).

A coral described and figured as *Papiliophyllum breviseptatum* Stumm by Latypov (in Volkova and Latypov, 1976, p. 12-13, Pl. 4, fig. 3a-v), from the Emsian Nelichen Formation on Krivoi Creek, Indigirka River drainage, northeastern Soviet Union, appears to be an unnamed species of *Dialeptophyllum*. *Papiliophyllum breviseptatum*, sensu stricto, which is known only from the late Pragian Kobeh Member of the McColley Canyon Formation of Nevada, has been monographed well by Merriam (1974, p. 50-52, Pl. 7, figs. 4-10; Pl. 8, figs. 1-8). Its cardinal septa are strongly dilated, especially in early stages, and its tabularial surfaces are broadly elevated inside a peripheral trough. The coral identified as *P. breviseptatum* Stumm by Latypov has concave tabularial surfaces, shows no septal dilation, and cannot be either congeneric or conspecific with Stumm's species.

The type and the species from the Nelichen Formation are the only species referred to *Dialeptophyllum* at this time. An undescribed coral, from a subsurface Horn Plateau reef in southwestern District of Mackenzie (Gulf et al. Trout River D-14 well, discussed by Fuller and Pollock, 1972, p. 153), appears to be related to *D. vopnii*, and is essentially the same age as *D. vopnii*. However, it is cerioid, and has a broader dissepimentarium with gently sloping surfaces near the periphery.

Etymology. From two Greek words, *dialeptos* and *phyllon*, meaning distinguishable and leaf.

Dialeptophyllum vopnii sp. nov.

Plate 3.5

Type series. Holotype, GSC 91288 and six paratypes, GSC 91289-91294, all from GSC locality C-41724. Twenty-four thin sections have been prepared from the type series.

Diagnosis. Species of *Dialeptophyllum* with maximum known length and mean diameter of 90 and 35 mm, respectively, and about 33 short major and minor septa at maturity. Presepiments large and steeply inclined.

Description. Corallum solitary, ceratoid, erect or slightly curved. Transverse sections are normally almost circular, but some mature corallites are elliptical. The maximum known length and mean diameter of the corallum are 90 and 35 mm, respectively. Although exteriors of the corals in the type series are poorly preserved, faint growth rings and very weak septal furrows were visible on some parts of some specimens before thin sectioning. Pronounced stages of rejuvenescence, affecting the dissepimentarium but not the tabularium, are typical of the species. The calice, which has not been observed directly, would be very deep, have steep sides, a moderately to strongly depressed base, and would lack a calicular platform.

In early stages, when the diameter of the corallum is 10 mm or less, the outer wall is relatively much thicker than it is in late stages. Locally, the wall is as thick as 1.0 mm in early stages; in late stages it is generally 0.08 to 0.25 mm thick. Much of the wall appears to consist of lamellar sclerenchyme, which continues on the sides of the otherwise thin and seemingly structureless septa. The mean diameter of the corallum at the earliest stage for which there is a transverse section is 5.5 mm; there are 15 undifferentiated septa in this section. These septa vary in length, but none reaches the centre of the corallum. During stages when the diameter of the corallum is 9 to 14 mm, there are 23 to 26 major septa, most of which extend from one third to one half of the distance to the axis. As viewed in transverse section, some major septa are straight, others are curved. Minor septa begin to develop when the corallum is about 9 mm in diameter. At first, two minor septa appear on opposite sides of a major septum that is slightly longer than many of the other major septa. The overall morphology of the corallum gives no indication as to whether the site of the first pair of minor septa is cardinal or counter. Further minor septa are added in an apparently haphazard manner. In early stages, minor septa are invariably fewer than major septa. In late stages, there are approximately 33 major and 33 minor septa. Major septa, in these late stages, are usually less than 6 mm long and are commonly discontinuous, being based on more than one presepiment; minor septa, in late stages, are very short and, apparently without exception, are interrupted by presepiments. No carina appears on any septa at any stage.

The first presepiments and dissepiments develop when the corallum is about 8 mm in diameter. Subsequently, five to eight rows of exceptionally long and only slightly inflated presepiments and dissepiments are added. Adaxial inclination of the dissepimentarial surfaces is very steep, in places, almost vertical. Tabulae are broad; many, despite strong convexity, are complete. Surfaces formed by the tabulae are moderately to strongly depressed. Spacing of the tabulae varies considerably. Thin layers of sclerenchyme overlie some tabularial and dissepimentarial surfaces.

Remarks. The unnamed and imperfectly known Russian species, discussed above, is said to have a maximum diameter of 25 mm, and is therefore smaller than *D. vopnii* (maximum diameter 35 mm), but has as many as 36 major septa (the maximum number of major septa in *D. vopnii* is not known to exceed 33). The septa in the Russian species are also relatively slightly longer than those of *D. vopnii*.

Etymology. The trivial name is a patronym in honour of L.K. Vopni, who contributed significantly to our understanding of the type Horn Plateau Reef.

Family CYATHOPHYLLIDAE Dana, 1846

Subfamily THRYPTOPHYLLINAE nov.

Type genus. Thryptophyllum gen. nov.

Diagnosis. Subfamily of the Cyathophyllidae with abundant presepiments, many of which resemble, and adaxially grade into, tabulae.

Discussion. The only known genus referred to the subfamily is *Thryptophyllum*, which is differentiated from genera of the Cyathophyllinae by its remarkable dissepimentarium. The trend exhibited by the horizontal skeletal elements of *Thryptophyllum* is similar to that seen in the lower Silurian genus *Ketophylloides* Lavrusevich (1971a, p. 93) and the lower Devonian genus *Reimanophyllum* Lavrusevich (1971b, p. 84). Both of these genera have a much more degenerate septal skeleton, and are unlikely to be cyathophyllids.

Characteristically, the presepiments in the Thryptophyllinae are neither as long, steeply inclined, nor as distinct from tabulae, as are the presepiments in many kyphophyllid, spongophyllid, or ptenophyllid genera.

Genus *Thryptophyllum* gen. nov.

Type species. Thryptophyllum undafundus sp. nov.

Diagnosis. Cerioid genus of cyathophyllid coral with poorly differentiated and commonly discontinuous septa. Both orders of septa are withdrawn from the axis and are commonly interrupted in periaxial regions of the corallite; in places, septa are reduced to isolated wavy fragments, or discrete carinae. The dissepimentarium includes abundant presepiments. Tabulae broad, generally forming gently concave tabularial surfaces that typically are not well differentiated from the dissepimentarial surfaces.

Discussion. The genus was almost certainly derived from *Minussiella* Bul'vanker (in Rzhonsnitskaya et al., 1952, p. 134), which has been discussed recently by the present author (Pedder, 1986, p. 474). In the recent discussion, it was suggested that *Minussiella* would be better placed in either the Columnariidae or the Cyathophyllidae, than in the Spongophyllidae, where it had been placed previously. After further study of both *Minussiella* and *Cyathophyllum* Goldfuss (1826, p. 51), including its rare type species *C. dianthus*, it is now certain that *Minussiella* is best placed in the Cyathophyllidae, because of its very fine and possibly nontrabecular septal structure.

Thryptophyllum differs from *Minussiella* in being cerioid, and having many more presepiments and shorter septa. The weak differentiation between tabularial and dissepimentarial surfaces in *Thryptophyllum undafundus* also separates it from species of *Minussiella*. *Thryptophyllum* has the same growth form as *Exilifrons* Crickmay (1968, p. 3, 4). However, as revised by Pedder (1977, p. 173-179), *Exilifrons* has long, mostly continuous and commonly crenulate septa, and has many small, globose dissepiments and only a few presepiments.

Spongophyllum romingeri Ehlers and Stumm (1949, p. 125-126, Pl. 1, figs. 1-3) is based on a holotype, prepared as two transverse and two longitudinal thin sections, from the lower Givetian Rockport Quarry Limestone in Presque Isle County, Michigan. Figures of the exterior of the corallum and thin sections, all of the holotype, including an originally unfigured transverse thin section, have been published by Ehlers and Kesling (1970, Pl. 15, figs. 41-43). *Spongophyllum romingeri* is certainly not congeneric with *Spongophyllum sedgwicki* Milne Edwards and Haime (1851, p. 425-426), the type species of *Spongophyllum* Milne Edwards and Haime (1851, p. 425), which is unfortunately based on a beach pebble neotype from south Devon. Photographs of the neotype, showing its large, steeply inclined dissepiments and narrow, well differentiated tabularium, have been published by Pedder (1980, Pl. 4, figs. 5-7) and Hill (1981, fig. 145, 3a, b). *Spongophyllum romingeri* apparently lacks yardarm carinae, but in all other respects resembles *Thryptophyllum undafundus* so closely, that it is referred to the same new genus without reservation. Because of its almost smooth septa, *Thryptophyllum romingeri* resembles typical examples of *Minussiella* more than *T. undafundus* does. It is also slightly older than *T. undafundus*, and may be a direct ancestor of it, especially as a seaway existed between the Michigan Basin and the Western Canadian Basin in early Givetian time. However, at present, there is no published record of *Minussiella* in the Michigan Basin faunas.

Etymology. From the Greek words, *thrypto*, meaning break, and *phyllon*, a leaf.

Thryptophyllum undafundus sp. nov.

Plates 3.6-3.9

Type series. Holotype, GSC 91295, and six paratypes, GSC 91296-91301, from GSC locality C-41712. One paratype, GSC 91302, from GSC locality C-41725. Twenty-nine thin sections have been prepared from the type series.

Diagnosis. Species of *Thryptophyllum* with mean adult corallite diameters of 9.0 to 15.2 mm. Septa variably crenulate and carinate, numbering 35 to 48 in fully grown corallites. Zigzag and fine, short, yardarm carinae both present. Some of the yardarm carinae are discrete. Presepiments and dissepiments generally large, commonly flat, or only slightly inwardly inclined. Locally, tabulae are not differentiated from presepiments; some tabulae are attached to the corallite wall.

Description. Corallum large and cerioid. None of the known specimens is complete. When the type locality was first visited by the author, the largest pieces of coralla available were more than 400 mm high and 300 mm in diameter. Most fully grown corallites have mean diameters of 9.0 to 13.0 mm, the maximum being 15.2 mm. The calice has not been observed directly and its depth is not known. It would probably have a narrow, intermittently developed platform and a shallow and locally ill-defined calicular pit. Increase is marginarial and nonparricidal. Normally, only one offset was produced by a polyp at one time. Longitudinal thin sections through the proximal region of an offset show that its basal tabularial surface is also a dissepimentarial surface of the parent corallite. New corallites enlarge slowly, and most are not completely separated by a continuous wall until the mean diameter of the offset approximates 7.0 mm.

Adjacent adult corallites share a narrow intercorallite wall, 0.05 to 0.2 mm thick. Where preservation is adequate, as in parts of GSC 91296 and GSC 91302, the intercorallite wall is seen to consist of a very fine (0.01-0.015 mm), dark, median layer between thicker, apparently structureless, outer layers. The relationship between these outer layers and the septal bases is unclear, although in GSC 91302, they appear to be continuous with the slender septal bases. Septa are thin (0.025-0.05 mm thick between carinae), radially arranged and poorly differentiated into two orders. Major septa are generally withdrawn from the axis, leaving an axial region, of 3 to 5 mm diameter in adult corallites, free of septa. Minor septa are short and, in places, entirely absent. Both orders of septa are commonly interrupted by presepiments, and locally may be reduced to wavy spine-like fragments, or discrete yardarm carinae. Yardarm carinae are fine and short. Fine zigzag carinae and crenulations also occur. The number of septa visible in transverse sections of corallites of a given diameter varies considerably. Corallites of less than 5 mm diameter have 0 to 31 septa; between 5 and 10 mm diameter there are 25 to 39 septa; corallites of more than 10 mm diameter have 35 to 48 septa. Trabeculae are either absent or extremely slender – preservation is inadequate to be certain of the fine structure.

Presepiments and dissepiments form a variable and unusual dissepimentarium. Where the dissepimentarium is distinct from the tabularium, there are three to five, rarely six, rows of generally moderately elongate, poorly inflated and inwardly inclined presepiments and dissepiments. More commonly, the dissepimentarium is indistinctly differentiated from the tabularium. In this case, the dissepimentarium consists mostly of a few, large, poorly inflated presepiments that are only slightly inclined toward the axis. In other cases, a single, large, horizontal plate extends from the axial region to the intercorallite wall. Some of these large plates and some of the large presepiments are curved to form broadly elevated horizontal surfaces approximately midway between the centre and periphery of the corallite. In rare, extreme cases, a single sinuous plate extends across almost the entire corallite. Tabulae are broad and commonly form gently concave tabularial surfaces. Normally, 10 to 16 tabulae are counted over a vertical distance of 10 mm, but locally in GSC 91297 and GSC 91300, they are so distantly spaced that only 4 occur over a vertical distance of 10 mm. No sclerenchymal deposit has been observed on any horizontal or vertical skeletal element in any of the specimens.

Remarks. *Thryptophyllum undafundus* differs from *T. romingeri* (Ehlers and Stumm) in having yardarm carinae and larger, more abundant presepiments, that are, locally, very similar to tabulae.

Etymology. The trivial name, which is a noun derived from the Latin word, *unda*, a wave, and *fundus*, a base, refers to the peculiar and distinctive horizontal surfaces of the species.

LOCALITY REGISTER

GSC locality C-41712. Horn Plateau Formation, reef flat macrofacies (Vopni and Lerbekmo, 1972a, Fig. 6; 1972b, p. 506-510); Middle *varcus* Zone, Givetian. 126 m on a bearing of 343° from Vopni's centre point of the type outcrop, 4.4 km west of the southwestern tip of Fawn Lake, southwestern District of Mackenzie; lat. 62°08'N, long. 117°41.5'W. Collected by A.E.H. Pedder, 1977, 1987. Fauna includes:

Tabulate coral
Zonophyllum spinosum (McLaren)
Grypophyllum craigi (McLaren)
Minussiella salcis (McLaren)
Thryptophyllum undafundus Pedder
Ozarkodina brevis (Bischoff and Ziegler)
Polygnathus ansatus Ziegler and Klapper
P. xylus ensensis Ziegler and Klapper

GSC locality C-41714. Horn Plateau Formation, reef flat macrofacies (Vopni and Lerbekmo, 1972a, Fig. 6; 1972b, p. 506-510); Middle *varcus* Zone, Givetian. 150 m on a bearing of 351° from Vopni's centre point of the type outcrop, 4.4 km west of the southwestern tip of Fawn Lake, southwestern District of Mackenzie; lat. 62°08'N, long. 117°41.5'W. Collected by A.E.H. Pedder, 1987. Fauna includes:

Thamnopora sp.
Zonophyllum spinosum (McLaren)
Agastophyllum eximium Pedder
Scissoplasma sp.
Psydracophyllum (?) sp. nov. (= *Australophyllum* (?) sp. cf. *A.* (?) *thomasae* sensu McLaren in McLaren and Norris (1964)
Minussiella conjuncta Pedder
M. cornus (McLaren)
Peripaedium gretneri McLaren
Leptagonia (?) sp.
Gypidula (?) sp.
Cranaena (?) *cryptonelloides* Norris
Conocardium sp.
Polygnathus ansatus Ziegler and Klapper ? (small form)

GSC locality C-41724. Horn Plateau Formation, reef flank macrofacies (Vopni and Lerbekmo, 1972a, Fig. 6; 1972b, p. 506-510); presumed Middle *varcus* Zone, Givetian. 294 m on a bearing of 57° from Vopni's centre point of the type outcrop, 4.4 km west of the southwestern tip of Fawn Lake, southwestern District of Mackenzie; lat. 62°08'N, long. 117°41.5'W. Collected by A.E.H. Pedder, 1987. Fauna includes:

Pachyfavosites alpenensis calveri (Swann)
Thamnopora sp.
Aulocystis sp.
Lythophyllum sp.
Zelophyllia sp.
Dialeptophyllum vopnii Pedder
Siphonophrentis sp.

Rhytidolasma boreale (McLaren)
Cylindrophyllum gruense McLaren
Fenestrate bryozoa
Schizophoria fascicostella Norris
Sphenophragmus sp. cf. *S. nanus* Imbrie
Leptagonia (?) *rhomboidalis* sensu Norris in McLaren and Norris, 1964
Eoschuchertella sp.
Spinulicosta sp.
Devonoproductus (?) sp. indet.
Productoid brachiopod
Hypothyridina sp.
Leiorhynchus (?) *matonabbee* Norris
Desquamatia sp.
Spinatrypa (*S.*) *hornensis* Norris
Athyris aquilonius Norris
A. (?) sp. (narrow form)
Eleutherokomma (?) *implana* Norris
Cyrtina sp.
Cranaena sp.
C. (?) *cryptonelloides* Norris
Smooth brachiopods (two forms)
Straparollus (*S.*) sp.
Conocardium sp.
Actinopteria sp.
Trilobite fragments
Ozarkodina brevis (Bischoff and Ziegler)

GSC locality C-41725. Horn Plateau Formation, reef flank macrofacies (Vopni and Lerbekmo, 1972a, Fig. 6; 1972b, p. 506-510); Middle *varcus* Zone, Givetian. 277 m on a bearing of 96° from Vopni's centre point of the type outcrop, 4.4 km west of the southwestern tip of Fawn Lake, southwestern District of Mackenzie; lat. 62°08'N, long. 117°41.5'W. Collected by A.E.H. Pedder, 1987. Fauna includes:

Thamnopora sp.
Rhytidolasma sp. nov.
Thryptophyllum undafundus Pedder
Desatrypa nasuta (Norris)
Warrenella-like brachiopod
Cranaena (?) sp. cf. *C.* (?) *cryptonelloides* Norris

GSC locality C-49444. Horn Plateau Formation, organic reef macrofacies (Vopni and Lerbekmo, 1972a, Fig. 6; 1972b, p. 506-510); Middle *varcus* Zone, Givetian. Northern margin of the surface outcrop of the type Horn Plateau Reef, 4.4 km west of the southwestern tip of Fawn Lake, southwestern District of Mackenzie; lat. 62°08'N, long. 117°41.5'W. Collected by A.E.H. Pedder, 1987. Fauna includes:

Clathrocoilona (?) sp.
Stachyodes (?) sp.
Agastophyllum eximium Pedder
Scissoplasma nebracis (McLaren)
Neospongophylloides sp. nov. (= *Sinospongophyllum* sp. cf. *S. planotabulatum* sensu McLaren in McLaren and Norris, 1964)
Grypophyllum craigi (McLaren)
Psydracophyllum (?) sp. nov. (= *Australophyllum* (?) sp. cf. *A.* (?) *thomasae* sensu McLaren in McLaren and Norris, 1964)
Peripaedium gretneri McLaren
Minussiella conjuncta Pedder
M. cornus (McLaren)
Desatrypa nasuta (Norris)
Cranaena (?) *cryptonelloides* Norris
Belodella sp.
Icriodus obliquimarginatus Bischoff and Ziegler
Ozarkodina brevis (Bischoff and Ziegler)
Polygnathus linguiformis Hinde (subsp. indet.)

GSC locality C-49445. Horn Plateau Formation, organic reef macrofacies (Vopni and Lerbekmo, 1972a, Fig. 6; 1972b, p. 506-510); Middle *varcus* Zone, Givetian. Northern margin of the surface outcrop of the type Horn Plateau Reef, 4.4 km west of the southwestern tip of Fawn Lake, southwestern District of Mackenzie; lat. 62°08'N, long. 117°41.5'W. Collected by A.E.H. Pedder, 1987. Fauna includes:

Agastophyllum eximium Pedder
Scissoplasma nebracis (McLaren)
Neospongophylloides sp. nov. (= *Sinospongophyllum* sp. cf. *S. planotabulatum* sensu McLaren in McLaren and Norris, 1964)
Grypophyllum craigi (McLaren)
Psydracophyllum (?) sp. nov. (= *Australophyllum* (?) sp. cf. *A.* (?) *thomasae* sensu McLaren in McLaren and Norris, 1964)
Minussiella conjuncta Pedder
M. cornus (McLaren)
Desatrypa nasuta (Norris)
Ozarkodina brevis (Bischoff and Ziegler)
Polygnathus linguiformis Hinde (morphotype indet.)
P. sp. indet.

ACKNOWLEDGMENTS

N.C. Meijer Drees, Geological Survey of Canada, accompanied the writer on one of his visits to the Horn Plateau Reef and assisted in collecting the sample from GSC locality C-41725. P. Johnston, Tyrrell Museum, identified *Actinopteria* sp. in the sample from GSC locality C-41724. F. Tourneur, Forschungs-Institut Senckenberg, identified *Pachyfavosites alpenensis calveri* from the same sample. C.W. Stearn, McGill University, identified stromatoporoids from GSC locality C-49444. T.T. Uyeno, Geological Survey of Canada, identified all of the conodonts in the faunas listed in the locality register. J.A. Kitchell, Museum of Paleontology at the University of Michigan, arranged for the loan to the author of the holotype of *Spongophyllum romingeri* Ehlers and Stumm. The writer is indebted to all of these colleagues for their assistance.

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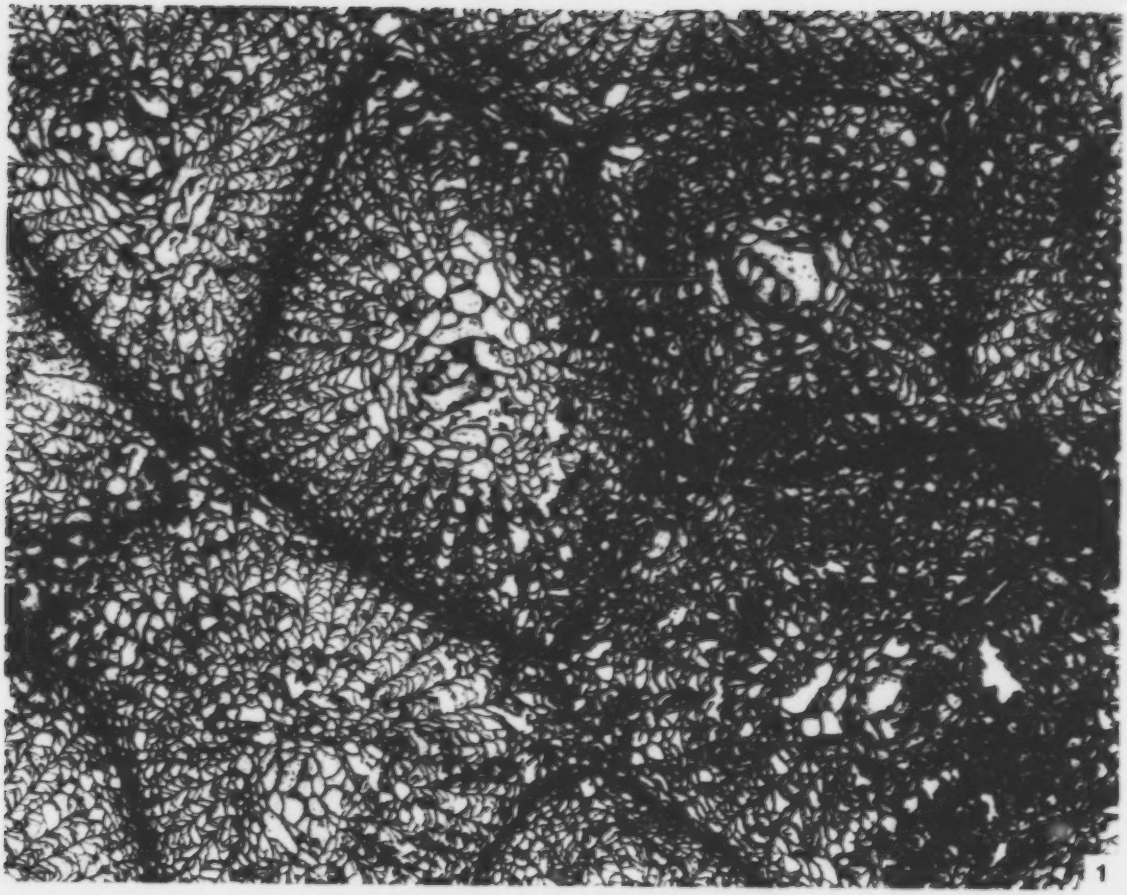
PLATE 3.1

Both figures enlarged x2

Agastophyllum eximium Pedder

Figures 1, 2. Transverse and longitudinal thin sections, holotype, GSC 91283, GSC locality C-49444.

PLATE 3.1



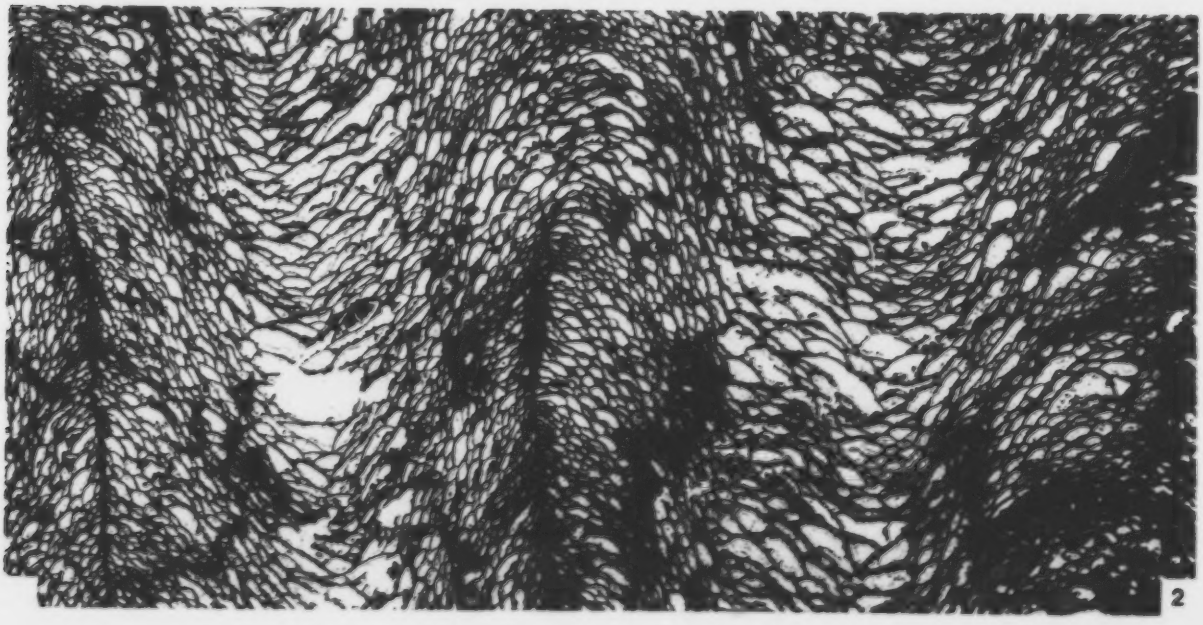


PLATE 3.2

All figures enlarged x2

Agastophyllum eximium Pedder

Figures 1, 2, 5. Longitudinal thin sections, holotype, GSC 91283, GSC locality C-49444.

Figures 3, 4. Transverse thin sections, holotype, GSC 91283, GSC locality C-49444.

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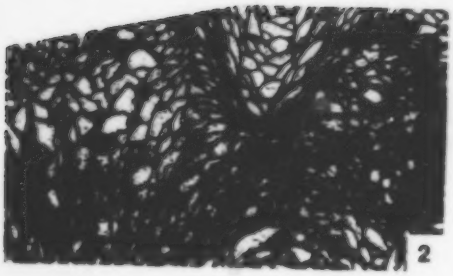
2

3

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PLATE 3.3

All figures enlarged x2

Agastophyllum eximium Pedder

Figures 1, 3. Transverse and longitudinal thin sections, paratype, GSC 91284, GSC locality C-49445.

Figure 2. Longitudinal thin section, paratype, GSC 91286, GSC locality 49444.

Figure 4. Transverse thin section, paratype, GSC 91285, GSC locality C-49444.

PLATE 3.3

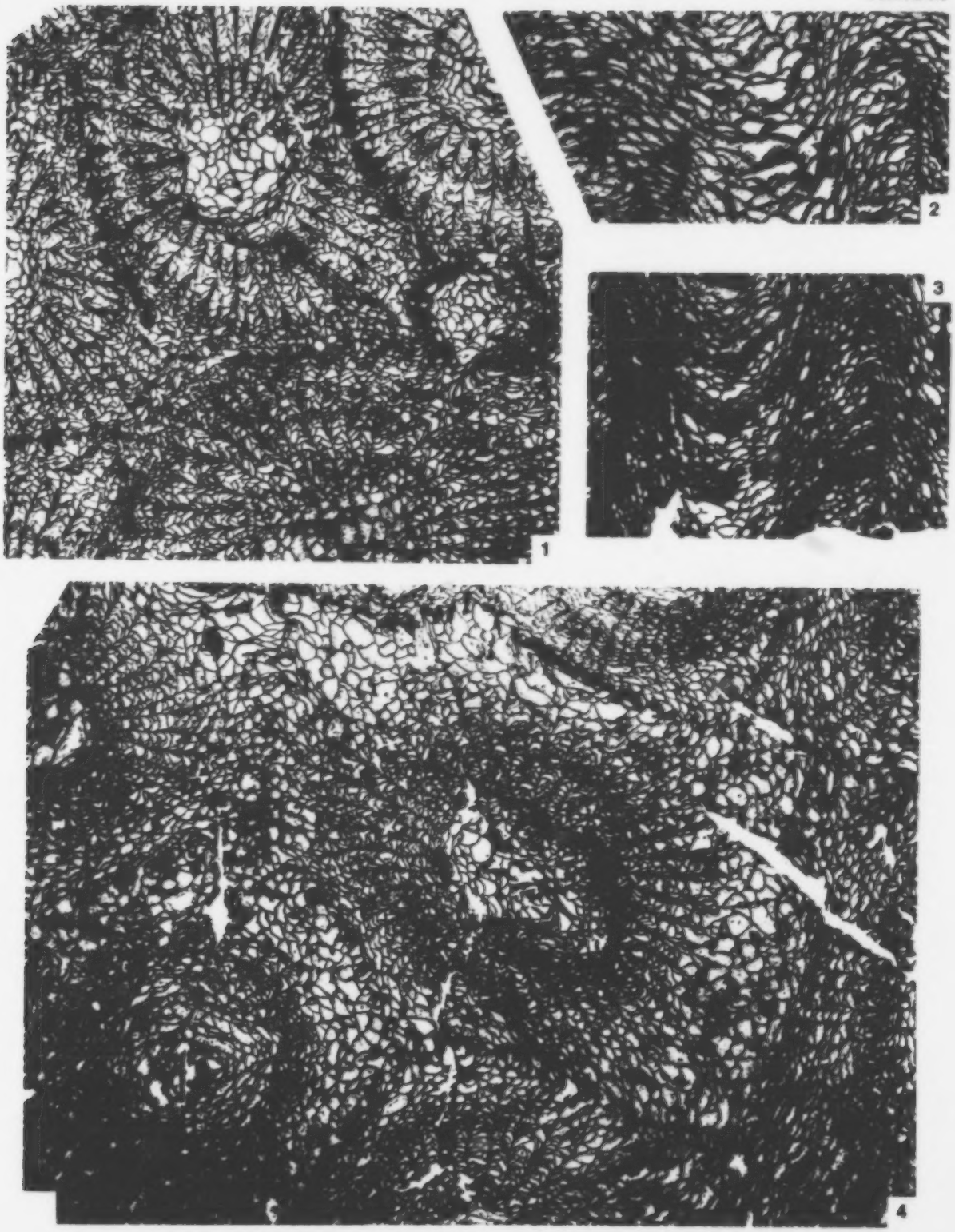


PLATE 3.4

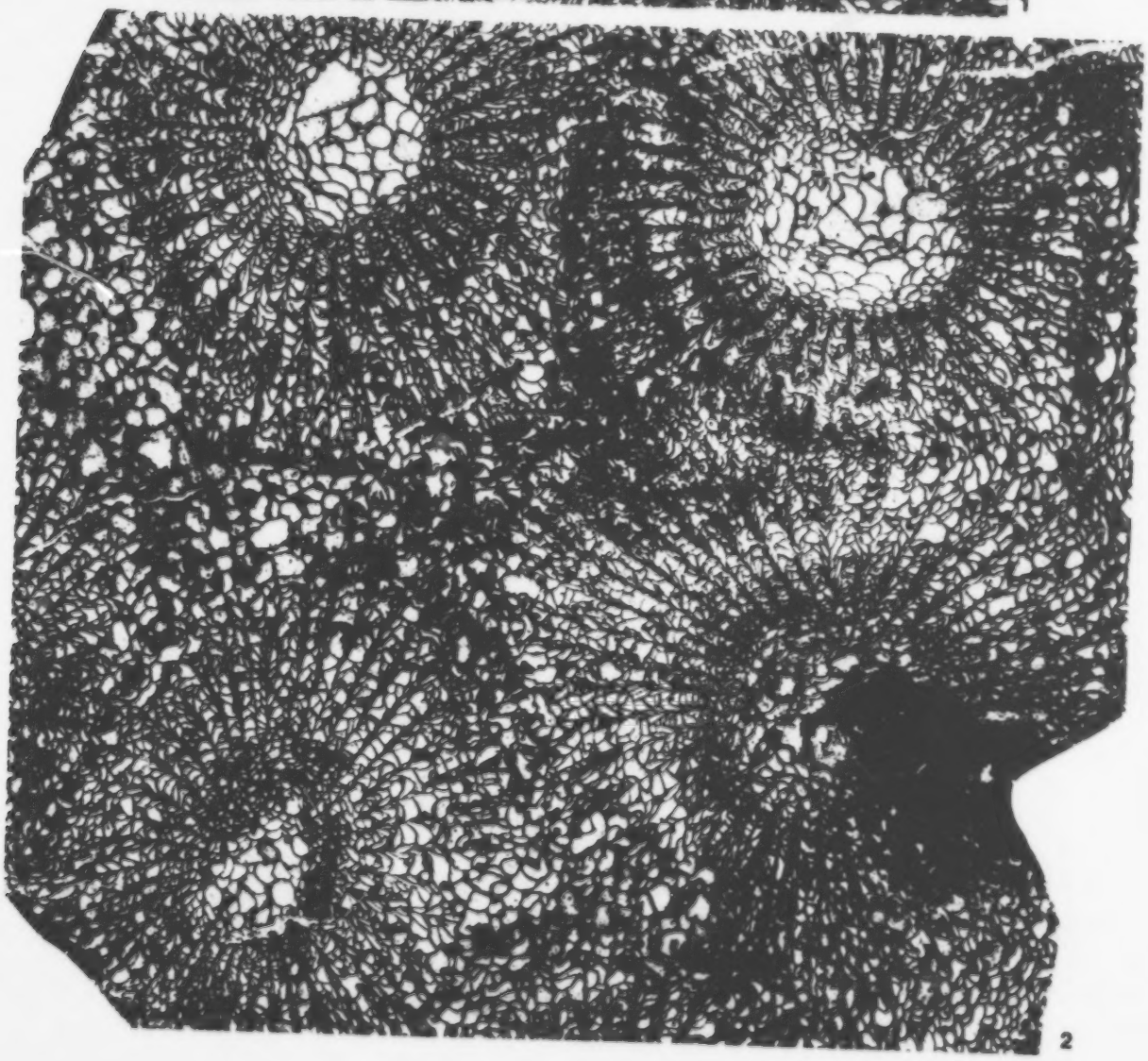
Both figures enlarged x2

Agastophyllum eximium Pedder

Figures 1, 2. Longitudinal and transverse thin sections, paratype, GSC 91287, GSC locality C-41714.

PLATE 3.4

1



2

PLATE 3.5

All figures enlarged x2;
all specimens from GSC locality C-41724

Dialeptophyllum vopnii gen. et sp. nov.

Figures	1, 4, 7, 9, 11, 17.	Three transverse and three longitudinal thin sections, holotype, GSC 91288.
Figures	2, 3.	Longitudinal and transverse thin sections, paratype, GSC 91290.
Figures	5, 8, 13.	Two transverse and one longitudinal thin section, paratype, GSC 91289.
Figures	6, 20.	Transverse and longitudinal thin sections, paratype, GSC 91292.
Figures	10, 15, 18, 19.	Three transverse and one longitudinal thin section, paratype, GSC 91291.
Figures	12, 14, 16.	Two longitudinal and one transverse thin section, paratype, GSC 91294.

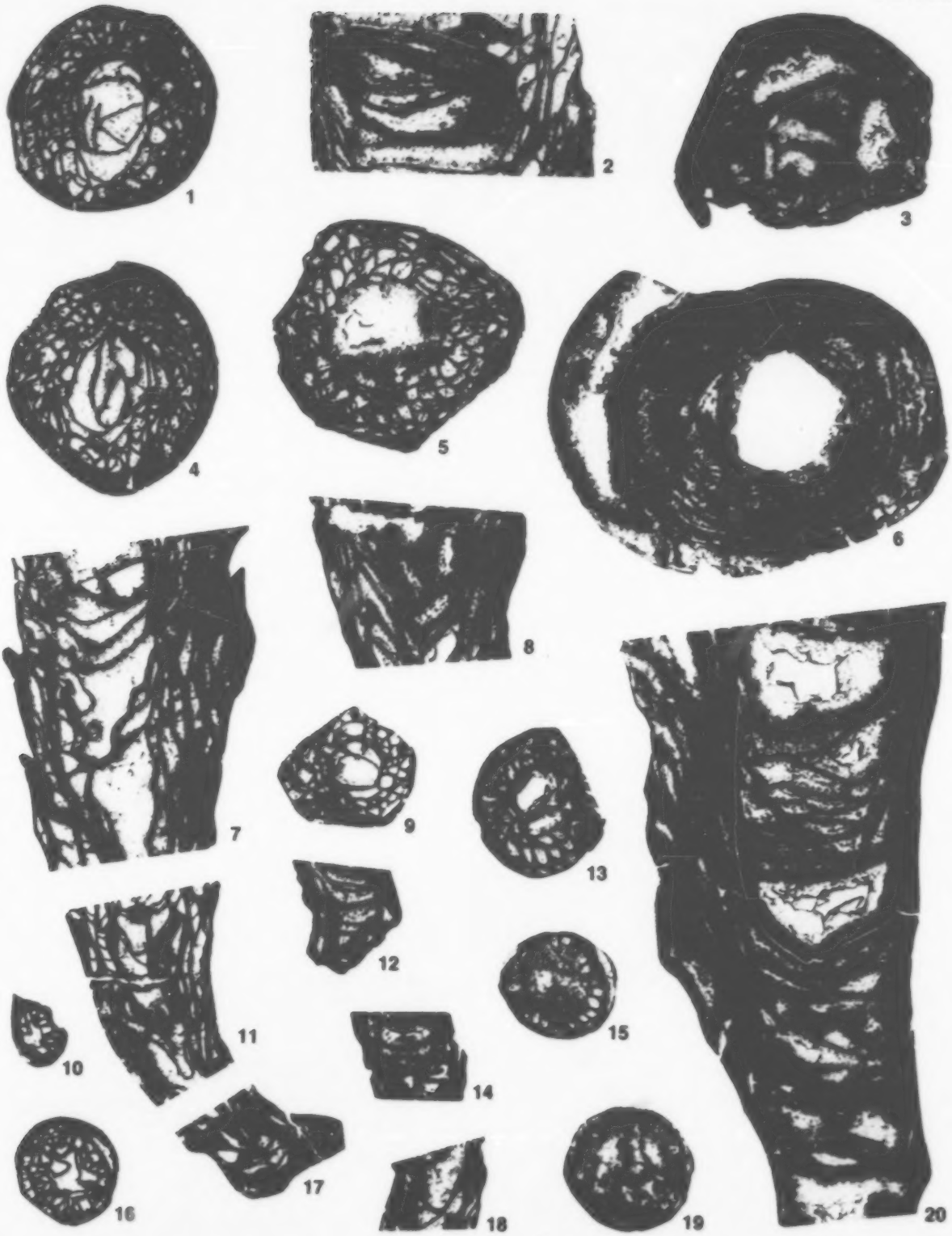

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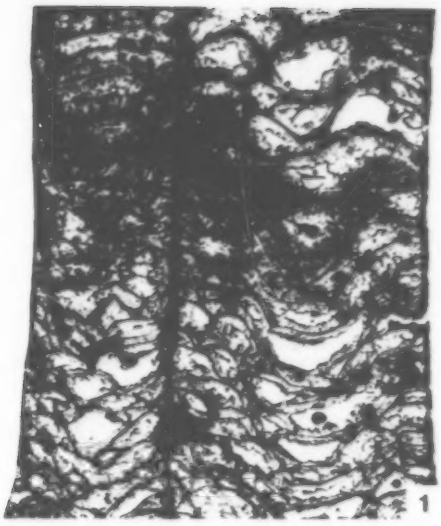
PLATE 3.6

All figures enlarged x3;
both specimens from GSC locality C-41712

Thryptophyllum undafundus gen. et sp. nov.

Figure 1. Longitudinal thin section, paratype, GSC 91300.

Figures 2-4. Longitudinal and two transverse thin sections, holotype, GSC 91295.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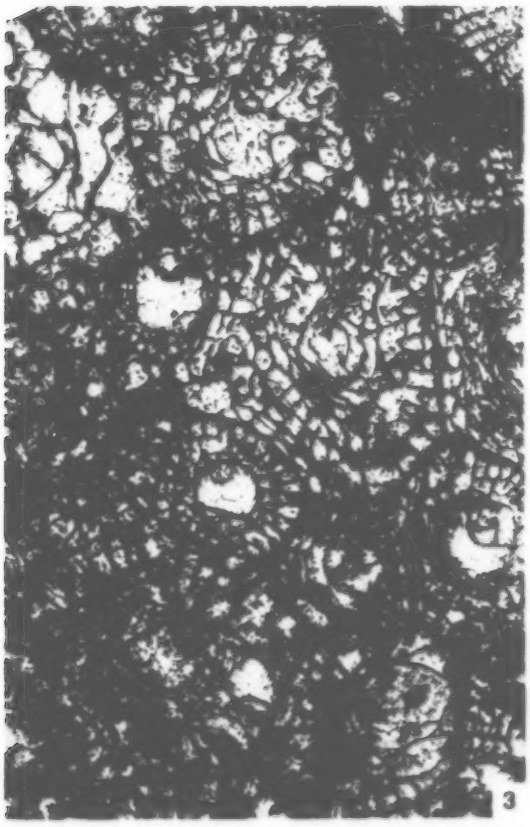
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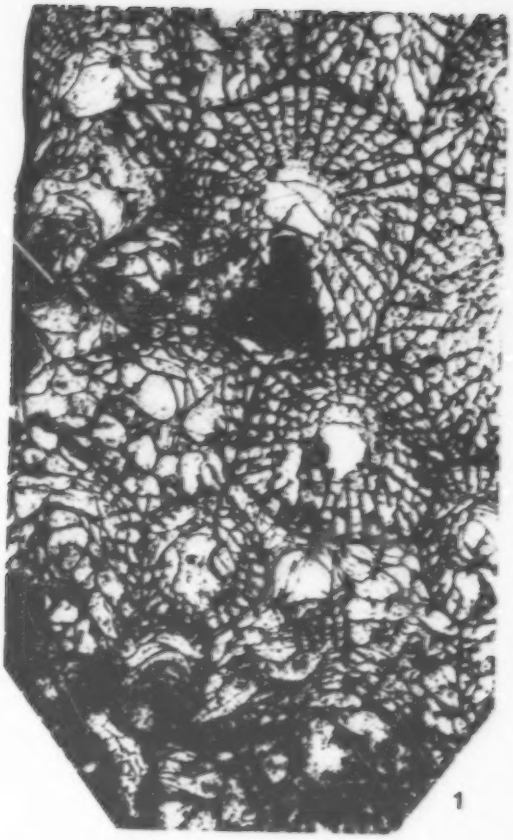
PLATE 3.7

All figures enlarged x3;
both specimens from GSC locality C-41712

Thryptophyllum undafundus gen. et sp. nov.

Figures 1, 2, 4, 5. Two transverse and two longitudinal thin sections, paratype, GSC 91296.

Figure 3. Longitudinal thin section, holotype, GSC 91295.



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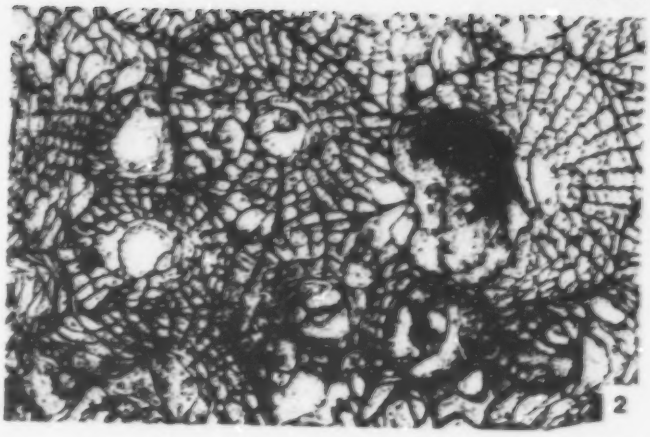

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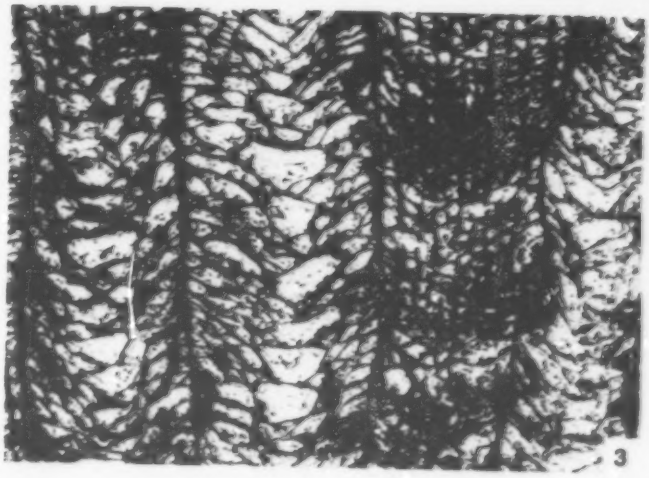

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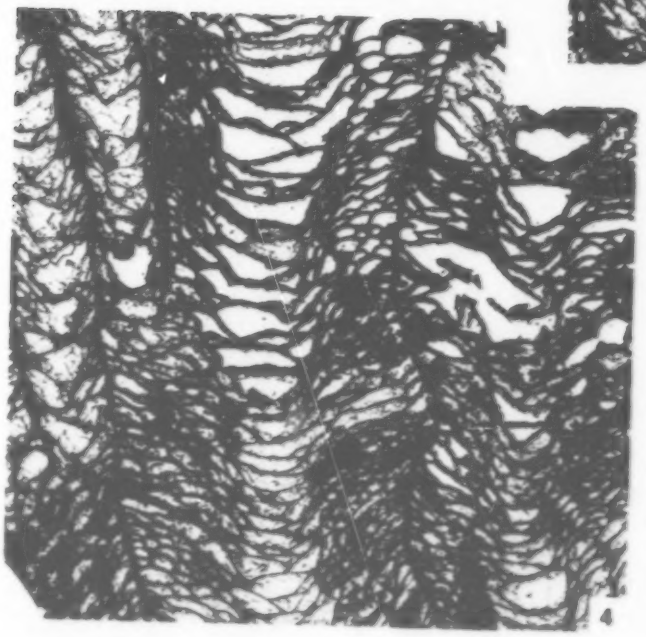

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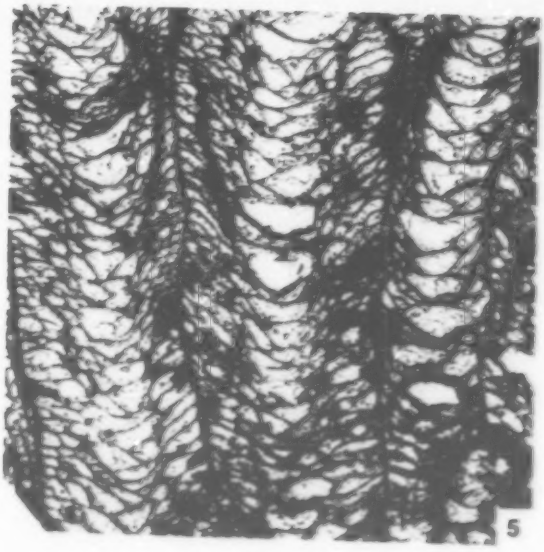

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PLATE 3.8

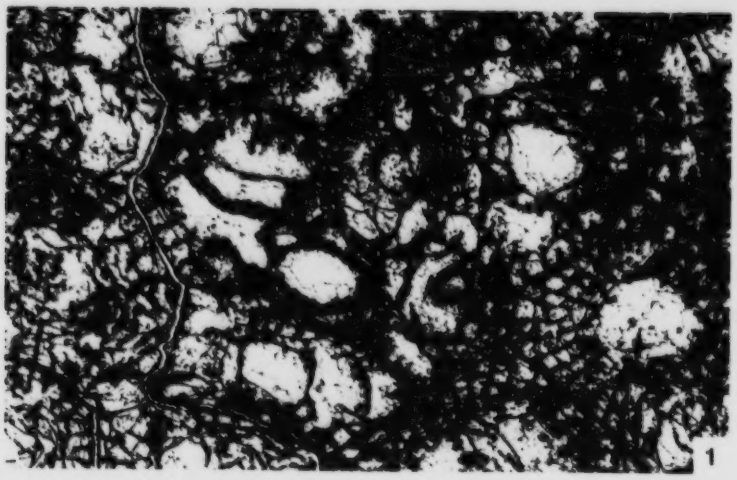
All figures enlarged x3;
all specimens from GSC locality C-41712

Thryptophyllum undafundus gen. et sp. nov.

Figures 1, 5. Transverse and longitudinal thin sections, paratype, GSC 91299.

Figures 2, 3. Longitudinal and transverse thin sections, paratype, GSC 91297.

Figure 4. Transverse thin section, paratype, GSC 91300.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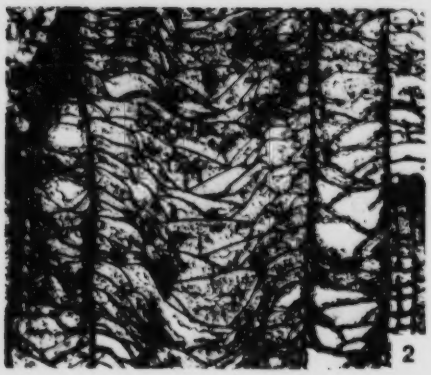
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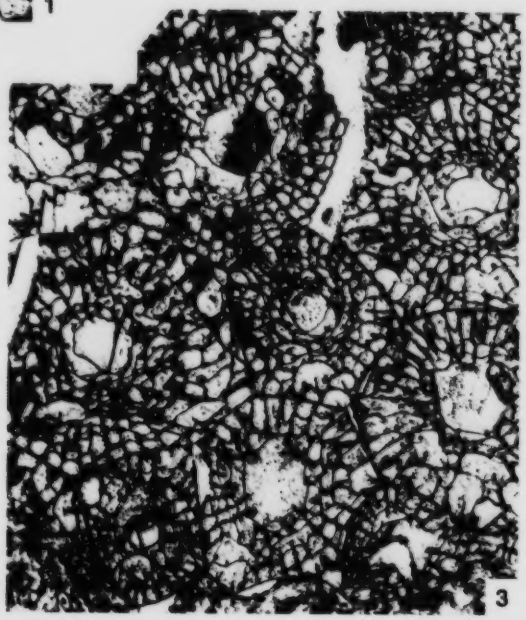
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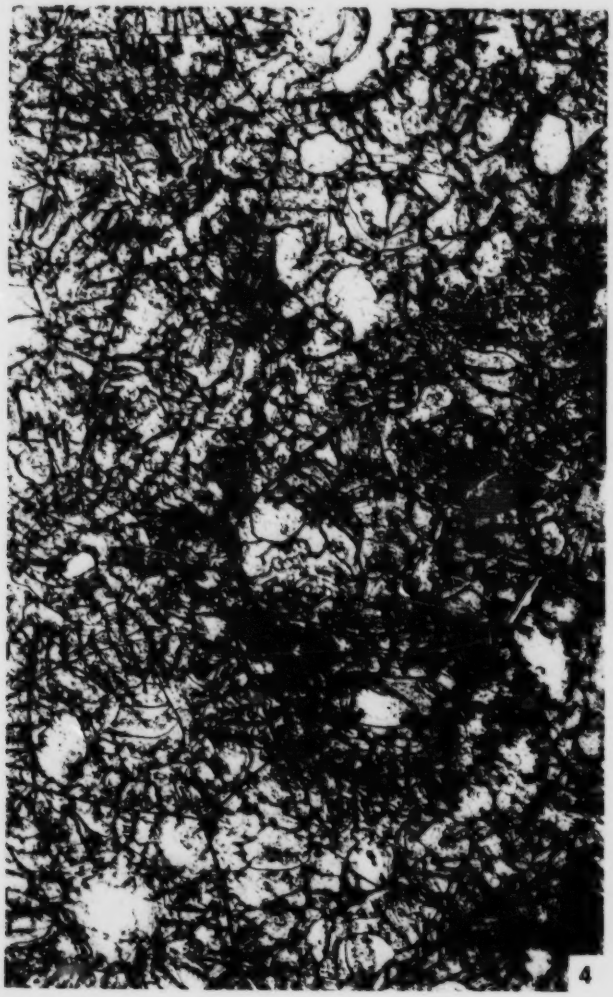
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PLATE 3.9

All figures enlarged x3

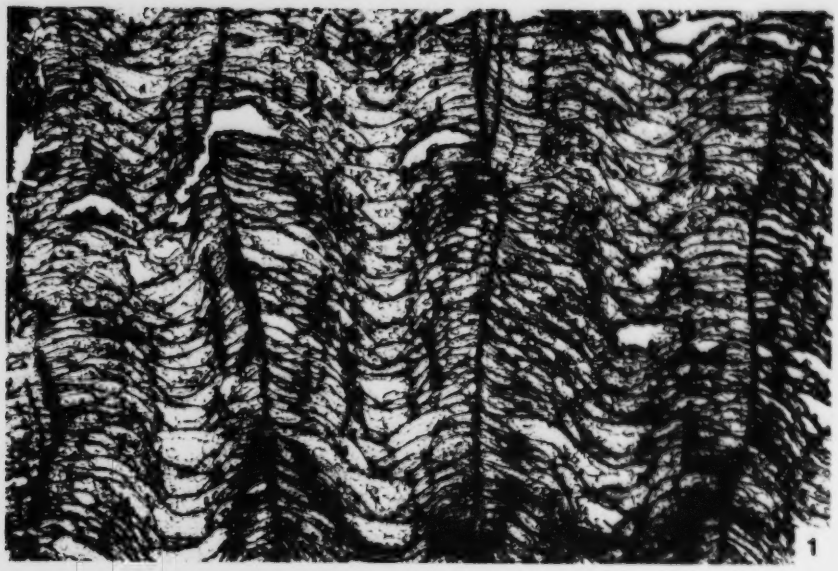
Thryptophyllum unifundus gen. et sp. nov.

Figures 1, 5. Longitudinal and transverse thin sections, paratype, GSC 91302, GSC locality C-41725.

Figures 2, 6. Longitudinal and transverse thin sections, paratype, GSC 91299, GSC locality C-41712.

Figure 3. Longitudinal thin section, paratype, GSC 91300, GSC locality C-41712.

Figure 4. Transverse thin section, paratype, GSC 91297, GSC locality C-41712.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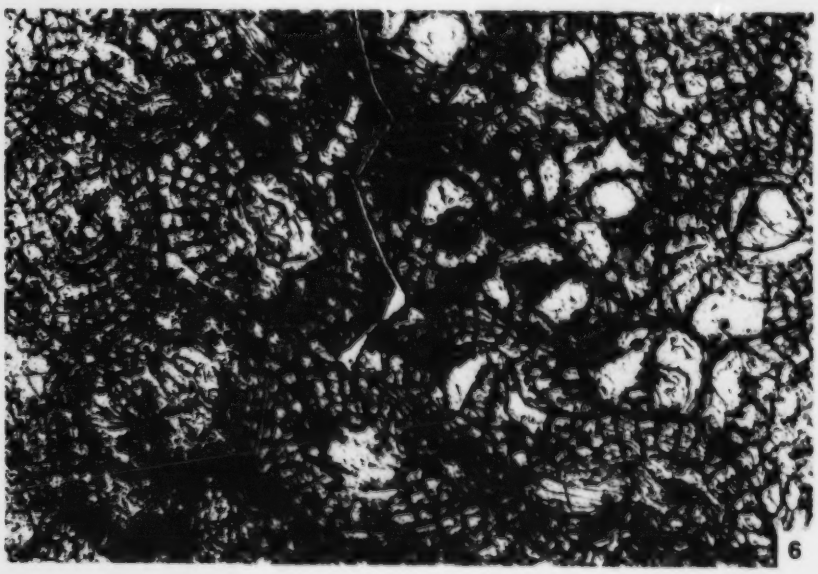
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VARIATION AND GENERIC IDENTITY OF *HELIOPHYLLUM BOREALE* MCLAREN, 1964, A MIDDLE DEVONIAN RUGOSE CORAL FROM WESTERN CANADA

A.E.H. Pedder[1]

Pedder, A.E.H., Variation and generic identity of ***Heliophyllum boreale*** *McLaren, 1964, a Middle Devonian rugose coral from Western Canada. In Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 396, p. 89-115, 1989.*

Abstract

Heliophyllum boreale was originally founded on two specimens from the type Horn Plateau Reef (Givetian, mostly, if not entirely Middle *varcus* Zone age at the surface) in southwestern District of Mackenzie. Both specimens resemble the type species of *Heliophyllum* in possessing yardarm carinae. A study of 35 topotypes of *H. boreale* reveals exceptionally wide variation in the septal morphology of the species, including unstable development of yardarm carinae. The study also demonstrates that the type specimens of *H. boreale* are atypical of the species as a whole. Five formae, designated alpha, beta, gamma, delta and zeta, are distinguished on the basis of septal morphology. It is argued that the species pertains to the Cyathophyllidae s.s. but not to any of the named genera of the family. *Rhytidolasma*, a new genus, is proposed for *H. boreale*.

Résumé

Heliophyllum boreale tire son origine de deux spécimens provenant du plateau récifal type Horn (Givétien, en grande partie, sinon entièrement de la partie intermédiaire de la Zone à *varcus* à la surface) dans le sud-ouest du district de Mackenzie. Les deux spécimens ressemblent aux espèces types d'*Heliophyllum* du fait qu'ils possèdent des carènes en vergue. Une étude de 35 topotypes de *H. boreale* révèle une variation exceptionnellement grande de la morphologie du septum de l'espèce, notamment la formation non stable de carènes en vergue. L'étude montre également que les spécimens types de *H. boreale* ne sont pas représentatifs de l'espèce dans son ensemble. Cinq formes, désignées alpha, béta, gamma, delta et zeta ont été distinguées en fonction de la morphologie du septum. On estime que cette espèce peut être attribuée aux Cyathophyllidae s.s. bien qu'à aucun des genres nommés de cette famille. Le nouveau genre *Rhytidolasma* est proposé pour *H. boreale*.

INTRODUCTION

Many of the rugose coral genera in use today are defined by morphological criteria revealed by just two sections – transverse and longitudinal – of the single type specimen of the type species of the genus. In such cases, nothing is known of the variation of the type species, even at its type locality. Hill (1981, p. 73) cited this shortcoming as one of two great impediments to precise coral taxonomy, the other being the incompleteness of description and imperfection of illustrations of many type specimens. Elsewhere in her monumental work, Hill (1981, p. 69) wrote that simplistic approaches to coral classification result in absurd unions and separations, and implied that classifications of corals should attempt to apply evolutionary theory and to express the most likely phylogenetic relationships, as well as degrees of morphological similarity and dissimilarity. The veracity of Hill's comments is beyond doubt, but there is a third serious impediment to coral taxonomy that she did not mention, and which, by its nature, is difficult to overcome. This is the extreme simplicity of the coral skeleton, which tends to mask the distinction between similarities due to close phylogenetic relationship and those resulting from convergent evolution.

The present work documents a case where inadequate knowledge of the range of variation of a species in a single population at its type locality resulted in a misunderstanding of the species' generic position. The work also provides an example of how reliance on a single morphological feature, such as the presence of yardarm carinae, in a group having a skeleton as simple as a rugosan corallum, can lead to unnatural classification. Yardarm carinae were evidently developed independently at different times in different lineages, and are not, in themselves, evidence of a congeneric relationship.

Heliophyllum boreale was established by McLaren (in McLaren and Norris, 1964), on the basis of five thin sections prepared from two specimens from the surface outcrop of the type Horn Plateau Reef (Figs. 4.1, 4.2). The age of the exposed part of this reef is believed to be mostly, if not entirely Middle *varcus* Zone (Pedder, 1986, p. 472; T.T. Uyeno, pers. comm., 1988). The overall similarity between *H. boreale* and *H. halli* Milne Edwards and Haime, the type species of *Heliophyllum*, especially with respect to the carinae in both species, makes the generic assignment to *Heliophyllum* seem reasonable. However, the present author has had the opportunity recently to collect 32 topotypes of *H. boreale*, from which 81 thin sections have been prepared. Examination of all of the material currently available reveals certain patterns of variation in the species, and also suggests strongly that the species is phylogenetically related more to the Cyathophyllidae than to the Zaphrentidae, which is where Oliver (1974, p. 174) and Hill (1981, p. 296) have both placed the genus *Heliophyllum*.

This discovery has important biogeographic implications, because the Cyathophyllidae s.s. appear to have had their origin in the Old World Faunal Realm, whereas the Zaphrentidae are believed to have originated in the Eastern North Americas Realm. For data on Devonian coral realms, readers are referred to papers by Oliver, 1977, and Oliver and Pedder (1979a, b and 1984).

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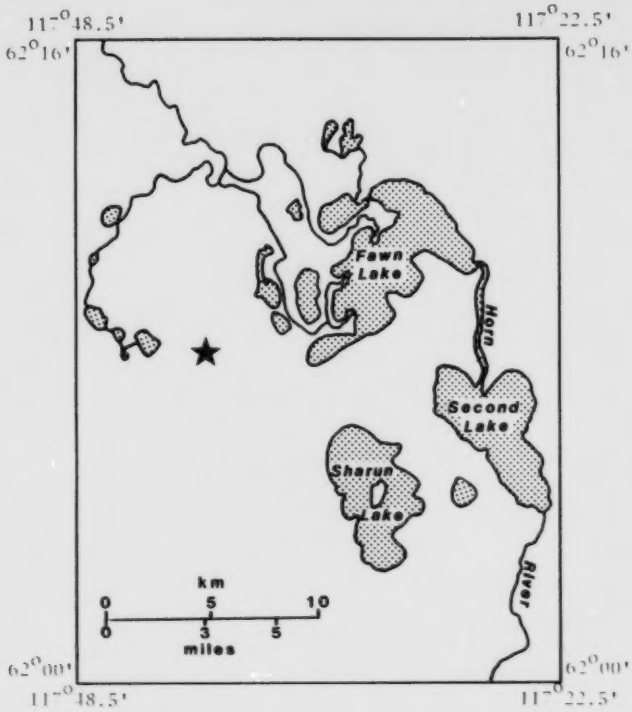

Figure 4.1. *Map of the Fawn Lake area, southwestern District of Mackenzie, with location of the type Horn Plateau Reef indicated by a star.*

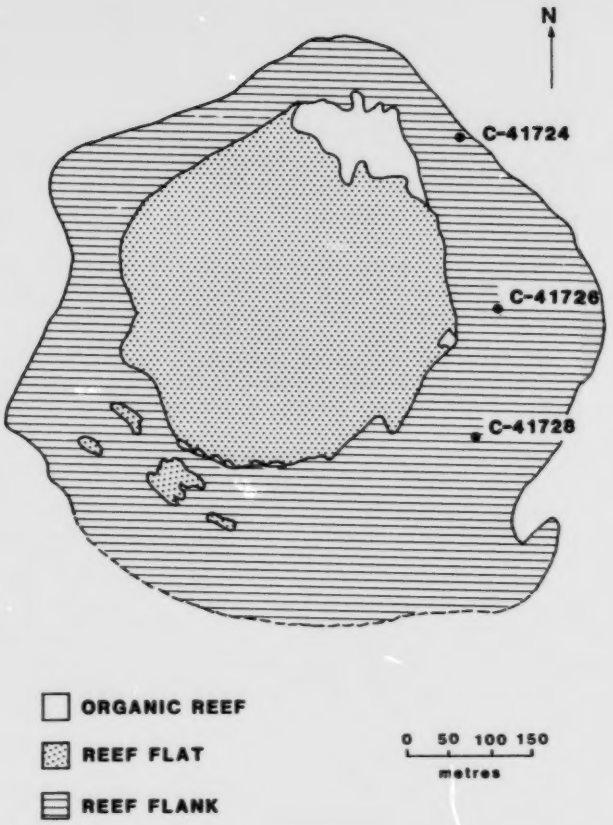

Figure 4.2. *Plan of macrofacies over the present surface of the type Horn Plateau Reef (after Vopni and Lerbekmo, 1972a, Fig. 6; 1972b, Fig. 6). The precise position of GSC locality 31001 is not known, but much of the collection, including the holotype of* ***Rhytidolasma boreale****, was probably made at GSC locality C-41724.* ***Rhytidolasma boreale*** *formae alpha, beta, gamma, epsilon and zeta occur at C-41724;* ***Rhytidolasma boreale*** *(McLaren) formae beta, gamma and delta occur at C-41726;* ***Rhytidolasma boreale*** *forma zeta occurs at C-41728.*

The purpose of this communication is to document the variation of the species originally named *Heliophyllum boreale* and to show that a new genus is required for it. The name proposed for this new genus is *Rhytidolasma.*

SYSTEMATIC PALEONTOLOGY

Phylum COELENTERATA Frey and Leuckart, 1847

Class ANTHOZOA Ehrenberg, 1834

Order STAURIIDA Verrill, 1865

Family ZAPHRENTIDAE Milne Edwards and Haime, 1850

Discussion. Coral genera with morphologies close to the morphologies of *Zaphrenthis, Cyathophyllum* and *Heliophyllum* mostly have fine trabeculae, and tend to develop similar strong, but usually thin, carinae. Although there is agreement among most workers that such genera are, at least, distantly related, classification of them is still disputed. There are several reasons for this, including silicification and lack of monographic studies of some critical American type species, the rarity and lack of knowledge concerning variation in taxonomically important species of *Cyathophyllum* and *Heliophyllum* in western Europe, and thirdly, the apparently synchronous appearance in different regions, of genera that otherwise would be considered to be in linear phylogenetic relationship with each other.

Revision of the families that, at different times, have held *Heliophyllum* and the genera mentioned above, is beyond the scope of the present work. However, it is necessary to explain why *Rhytidolasma* and *Heliophyllum* are placed in different families. On the basis of Oliver's (1960, p. 17-18) discussion of *Zaphrenthis phrygia* Rafinesque and Clifford, the type species of *Zaphrenthis*, and figures of topotypes of the species published by Hill (1981, p. 295, Fig. 191.4a-c), *Heliophyllum* is closely related to *Zaphrenthis.* Both have strong bilateral symmetry developed in early stages and a cardinal fossula in later stages. Variable, but definite, axial dilation of the septa, caused by sclerenchymal investment of the septa in the tabularium, is invariably present in early stages of *Heliophyllum* and is believed to be present in *Zaphrenthis.* Yardarm carinae are abundant in the dissepimentaria of both genera. These common features unite the two genera in the Zaphrentidae. *Rhytidolasma*, on the other hand, resembles *Cyathophyllum* in having negligible septal dilation and essentially radial symmetry in early stages. Yardarm carinae are, on the whole, less abundant than zigzag carinae in *Rhytidolasma*, as is the case in typical

species of *Cyathophyllum* and other genera assigned to the Cyathophyllidae. Finally, the consistently narrow, sagging tabularial surfaces of *Rhytidolasma* are very different from the broadly elevated tabularial surfaces of *Heliophyllum* illustrated in figures 1, 4 and 9 of Plate 4.1 of this paper. The tabularium of *Rhytidolasma* relates it to *Minussiella*, which, on the basis of other morphological criteria, is clearly a cyathophyllid, rather than a zaphrentid coral.

Genus *Heliophyllum* Hall, 1846

Cyathophyllum (*Heliophyllum*) Hall in Dana, 1846, p. 183.

Heliophyllum, Milne Edwards and Haime, 1850, p. lxix.

Heliogonium Chapman, 1893, p. 45.

?*Heliophylloides* Stumm, 1949, p. 18.

Type species of Heliophyllum. Strombodes helianthoides? sensu Hall, 1843, p. 209, 210, Fig. 87,3 on page 209, repeated as Figure 3 in Table 48 of the tables of organic remains. Hamilton Group; figured specimen probably from the Ludlowville Formation of Lower *varcus* Zone age (Wells, 1937, p. 9; Sparling, 1985, Fig. 1; 1988, Fig. 19); figured specimen from York, Livingston County; others from Moscow (now called Leicester), Livingston County, and Seneca Lake, New York. Hall believed his material of the type species to be questionably synonymous with *Cyathophyllum helianthoides* Goldfuss (1826, p. 61, Pl. 20, fig. 2a-k) and also questionably with corals identified as *Strombodes helianthoides* (Goldfuss) by Phillips (1841, p. 10, 11, Pl. 5, fig. 13 alpha a-e, beta a, b). Figures 2a-k of Goldfuss' Plate 20 depict the exteriors of eight or nine corals. One of these (fig. 2c) was chosen as the lectotype of *Cyathophyllum helianthoides* Goldfuss by Stumm (1949, p. 22), although its internal morphology and generic position are not known. Stumm believed the lectotype to be an acanthophyllid (= ptenophyllid) coral, but Schulz (1883, p. 237) and Birenheide (1963, p. 383) have both speculated that it may be conspecific with the coral that Schulz (1883, p. 237-238, Pl. 21, fig. 8) named *Heliophyllum spongiosum*. Schulz's species is considered to be a species of *Cyathophyllum* by Birenheide (1963, p. 383; 1978, p. 73). Two of the other Goldfuss specimens (fig. 2d, e) are possibly synonymous with the lectotype. Birenheide (1963, p. 415) overlooked Stumm's choice of lectotype and chose the specimen illustrated in Goldfuss' figure 2e as the lectotype of *Cyathophyllum helianthoides*. He regarded it as a species of *Dohmophyllum*. The specimens depicted in figures 2i and 2k of Goldfuss' Plate 20 are probably conspecific with a cerioid coral named *Astroblastodiscus planus* by Ludwig (1866, p. 228, Pl. 67, fig. 1a, b), which is referred to the genus *Peripaedium* by Birenheide (1963, p. 398; 1978, p. 78). The generic identities of the corals illustrated in figures a, b, f-h of Goldfuss' (1826) Plate 20 and of those illustrated in Phillips' 1841 work are not known.

With all this uncertainty regarding the type species of *Heliophyllum*, Milne Edwards and Haime's (1850, p. lxix) decision to rename it *Heliophyllum halli* is fully justified.

Hall's original figured specimen of *H. halli* has been mislaid. However, the specimen illustrated by Milne Edwards and Haime (1851, Pl. 7, fig. 6-6b) was found recently in Belgium and is now in Paris (Muséum National d'Histoire Naturelle IP S.11661). It has been thin sectioned, and has been made the neotype of the species by Coen-Aubert (1987, p. 152, 155, Pl. 1, figs. 1, 2). It is believed to be from the Moscow Formation, which is Lower to Middle *varcus* Zone age (Sparling, 1985, Fig. 1; 1988, Fig. 19), at Leicester (previously called Moscow), Livingston County, New York.

Type species of Heliogonium. Heliophyllum confluens Hall, 1877, Pl. 26, figs. 3, 4 (by subsequent designation of Stumm, 1949, p. 21). Hamilton Group; locality not published, but said to be Genesee Valley, New York, in the American Museum of Natural History type catalogue.

Type species of Heliophylloides. Cyathophyllum brevicorne Davis, 1887, Pl. 79, figs. 13-18. Jeffersonville Limestone; Falls of the Ohio, between Jeffersonville, Indiana and Louisville, Kentucky. According to Stumm (1965, p. 38), the type horizon is from above the coral zone of the Jeffersonville Limestone. If this is correct, the type horizon is early Eifelian in age, probably *costatus* Zone (Oliver, 1968, Fig. 1; Sparling, 1985, Fig. 1). Stumm (1949, p. 18) chose the specimen illustrated in figure 17 of Davis' (1887) Plate 79 as lectotype for the species. Later, he placed the species in synonymy with *Heliophyllum venatum* Hall (1882, p. 46; 1883, p. 306, Pl. 26, figs. 17, 18). The lectotype of *Cystiphyllum brevicorne* has not been prepared in any way, but exterior views have been reillustrated twice by Stumm (1949, Pl. 8, fig. 5; 1965, Pl. 33, figs. 7, 8).

Description. Corallum commonly solitary, mostly turbinate to ceratoid, less commonly weakly aggregated to massive, either cerioid or astreoid. Calice characteristically moderately deep with a broad axial pit, a steeply inclined lower calice wall, a broad horizontal or gently inclined peripheral platform, and a shallow cardinal fossula.

Major septa tend to be long and bilaterally arranged about the cardinal-counter plane. Mature septa are usually attenuated, especially in the dissepimentarium; in early ontogenetic stages, septa are moderately to heavily dilated in the tabularium. Carinae are abundant and prominent in the dissepimentarium, rare in the tabularium; long yardarm carinae predominate over short zigzag carinae. Each carina may comprise a single monacanthine trabecula, or it may be a compound trabecula with prominently branching elements, or a compound trabecula that branches infrequently at a very low angle.

Outer corallite wall thin, locally degenerate in massive forms. Dissepiments mostly relatively small, globose, numerous, forming many rows in late stages of development. Tabulae are incomplete and form broadly elevated tabularial surfaces, although these surfaces may be somewhat depressed periaxially where the major septa are withdrawn appreciably from the axis.

Discussion. The description given above draws heavily from a diagnosis prepared by Oliver (1974, p. 174) and from the study by Sorauf and Oliver (1976) on the carinae of the genus. Morphologically typical examples of *Heliophyllum halli* are illustrated in Plate 4.1 of this paper.

Heliophyllum needs to be researched much more than it has been hitherto, especially to determine its relationship to *Zaphrenthis*, and to establish whether the massive species should be retained in it. Chapman (1893, p. 45) coined the generic name *Heliogonium*, but defined it merely as "tesselated forms of *Heliophyllum*" from Silurian and Devonian strata. Type or component species were not cited. In this context, the word "tesselated", from the Latin word for a small square stone, presumably means massive, like the syntype of *Heliophyllum confluens*, figured in Plate 27 of Hall's 1877 work. This specimen, which is from the Hamilton Group, apparently Ludlowville Formation, at York in Livingston County, New York, has been made the lectotype

of *H. confluens* by Wells (1937, p. 10). Stumm (1949, p. 21) wanted to put *Heliogonium* in synonymy with *Heliophyllum* and deliberately chose Hall's other figured specimen of *H. confluens*, which is a smaller and less obviously massive colony, as the type species of *Heliogonium*. Neither of the relevant specimens has been thin sectioned, and it is not known whether they are conspecific, or how they compare with *Heliophyllum halli*. Despite the original lack of a designated type species, the generic name is available under the authorship and date of Chapman, 1893 [International Code of Zoological Nomenclature, Article 11(c)(i)], provided the limited edition of 130 bound copies of Hall's 1877 work (Wells, 1937, p. 6) satifies I.C.Z.N. Article 8(a)(3), where it is ruled that a valid publication "must have been produced in an edition containing simultaneously obtainable copies by a method that assures numerous identical copies".

The silicified lectotype of *Cyathophyllum brevicorne* Davies would probably not yield good thin sections. Stumm (1949, p. 18) noted the presence of yardarm carinae in the dissepimentarium, and his figures, especially figure 8 in Plate 33 of his 1965 work, seem to support this. Ivanovskiy (1976, p. 80) believed that the species is possibly a *Moravophyllum*, but, because of the yardarm carinae and the species' provenance, it is very much more likely to belong to *Heliophyllum*.

Family CYATHOPHYLLIDAE Dana, 1846

Discussion. The closely related core genera of this family are *Cyathophyllum*, which probably includes *Orthocyathus* (see Hill, 1981, p. 304), *Beiliucyathus* described by Yu and Kuang (1982, p. 59-62, 79, Textfig. 4, Pl. 1, figs. 1-5, 7-9), *Exilifrons* (= *Pinyonastraea*, see Pedder, 1977, p. 174-175), *Minussiella* (= *Pseudocampophyllum*, see Pedder, 1986, p. 474), *Peripaedium* (= *Keriophyllum*, see Birenheide, 1963, p. 389-392) and the new genus described below. *Spinophyllum*, whose type species is inadequately known, should be added here possibly, although it may prove to be more closely related to *Hexagonaria*. The typical cyathophyllid genera are united by their narrow outer wall, fine trabeculae, septa that are thin in the dissepimentarium in all of the genera and are characteristically undulant in several of them, variable fine carinae, general lack of excessive stereome – particularly in early stages, and a poorly defined bilateral or radial symmetry in all stages.

Genus *Rhytidolasma* gen. nov.

Type species. *Heliophyllum boreale* McLaren in McLaren and Norris, 1964.

Diagnosis. Cyathophyllid corals having a solitary corallum, undulant to carinate septa, the carinae being of both the zigzag and yardarm kind, and a narrow, distinctly concave tabularium.

Discussion. *Cyathophyllum* s.s. differs in being fasciculate to subcerioid, and has weakly carinate septa and a broader tabularium with generally flat surfaces. *Beiliucyathus* is a solitary to weakly fasciculate genus with a relatively broad, upwardly domed tabularium. *Exilifrons* differs from the new genus in being phaceloid, subcerioid, or ceriod, and by having a relatively broad upwardly domed tabularium. *Peripaedium* s.s. is a solitary genus. *Peripaedium turbinatum* (Goldfuss), the type species, and *P. crassum* (Haller), a similar species, have been well figured by Haller (1936) (see Birenheide, 1963, p. 390, 394, for synonymies). They differ from *Rhytidolasma* by having convex tabularial surfaces formed of numerous vesicular tabulae.

The type, and at least one other species of *Chalcidophyllum*, resemble *Rhytidolasma* in some respects. *Chalcidophyllum*, which may have been confined to Emsian seas of eastern Australia, differs from the new genus by lacking carinae and septal undulations. Furthermore, its outer wall is invariably turned inward along the septal furrows, where it passes imperceptibly into the peripheral ends of the septa (Pedder, 1965, Pl. 34, fig. 2). This feature is extremely rare in *Rhytidolasma*.

Minussiella appears to be morphologically the closest genus to *Rhytidolasma*, and may well be directly ancestral to it. It differs from *Rhytidolasma* in that it is commonly fasciculate to subceriod, its septa are much less carinate and lack yardarm carinae entirely, and its tabularium is relatively broader and not consistently depressed.

Cai (in Cai and Zeng, 1983, p. 212) has erected a monospecific genus named *Qinghephyllum*, based on *Q. junggarense* Cai (in Cai and Zeng, 1983, p. 212, Pl. 36, figs. 7, 8) from Lower Devonian strata in Qinghe County, Xinjiang Province, northwestern China. Cai thought *Qinghephyllum* to be a digonophyllid genus distinguished from *Dialythophyllum*, which according to Pedder and McLean (1982, p. 75) is a junior synonym of *Lekanophyllum*, by its continuous carinate septa and broad, locally complete tabulae. Early stages of *Q. junggarense* are unknown and published figures of adult stages are inadequate. The species appears to have well developed septa, numerous small globose dissepiments, a clearly defined tabularium, and, as such, may belong to the Cyathophyllidae. In any case, it appears to be distinguished from species of *Rhytidolasma* by having numerous small globose dissepiments and a relatively broad tabularium.

McLaren compared the type species of *Rhytidolasma* to both *Heliophyllum halli* and *H. elongatum* Stumm and Tyler (1962, p. 267-268, Pl. 2, figs. 1, 2). Morphology of the early stages of *H. elongatum* is unknown; figures of the adult tabularium are entirely consistent with an assignment to *Heliophyllum*. No other species is referred to *Rhytidolasma* at this time.

Etymology. The name *Rhytidolasma* is derived from the Greek words, *rhytis*, meaning fold or wrinkle, and *elasma*, a plate. Crenulations in the septa are highly characteristic of two of the most abundant formae recognized in the type species.

Rhytidolasma boreale (McLaren)

Plates 4.2-4.9

Heliophyllum borealis McLaren in McLaren and Norris, 1964, p. 15-16, Pl. 5, fig. 1a-c; Pl. 6, fig. 1a, b.

Heliophyllum borealis McLaren. Vopni, 1969, Pl. 4, figs. 21, 22.

Heliophyllum borealis McLaren. Vopni and Lerbekmo, 1972b, p. 513.

Material. Holotype and paratype, GSC 16483, 16484, from GSC locality 31001. Fourteen figured specimens, GSC 91309-91322, from GSC locality C-41724. Three figured specimens, GSC 91323-91325, from GSC locality

C-41726. Two figured specimens, GSC 91326, 91327, from GSC locality C-41728. About sixteen unregistered specimens, including Vopni's material, from the type Horn Plateau Reef.

Description. Corallum solitary – no budding observed in more than 35 studied specimens; trochoid or ceratoid, rarely turbinate (<2%) in early to middle stages, becoming subcylindrical in late stages of development. Maximum known length, measured along the convex side, 165 mm (GSC 91320 before sectioning). Transverse sections are commonly slightly elliptical. The maximum known mean diameter is 52 mm (GSC 91309), but most specimens ceased to enlarge after attaining a mean diameter of about 45 mm. One specimen (GSC 91318) apparently ceased to enlarge after reaching a mean diameter of only about 20 mm. The calice has not been observed directly in topotypic material, but would have had a very narrow, peripheral, calicular platform and a moderately deep subconical calicular pit. In some transverse sections, the calicular pit has a key-hole shape due to the development of weak cardinal fossula on the convex side of the corallum. Typically, 15 to 25 very fine growth rings occur between coarser annulations (Pl. 4.3, fig. 1); significant rejuvenescences are not evident in the available material. Interseptal ridges, which are much broader than the septal furrows, vary from being almost flat to distinctly convex. No radiciform process has been seen.

Outer wall thin, commonly partly eroded in topotypic specimens, 0.08 to 0.15 mm thick in most specimens; maximum thickness measured 0.3 mm (locally in GSC 91311), minimum 0.06 mm (locally in GSC 91320). The outer wall normally embeds, or is abutted by the peripheral ends of the septa, provided there is no presepiment, but in one specimen (GSC 91324), the outer wall is strongly invaginated along some septal furrows, and, in these places, is continuous with the septal bases.

At 5 mm mean corallite diameter, which is the earliest stage represented in the available transverse thin sections (GSC 91321), there are 17 or 18, roughly radially arranged, short major septa, and traces of a few minor septa adjacent to the corallite wall. There is no septal dilation, so that the interseptal loculi are much broader than the septa. A few relatively coarse yardarm and zigzag carinae are present.

During stages when the mean corallite diameter is 7 to 19 mm, the arrangement of septa is either crudely radial, or crudely bilateral about the cardinal-counter plane. There are from 21 to 29 major septa and fewer, short, peripherally situated minor septa. Major septa are variably withdrawn from the axis. The cardinal septum and, in some sections, the alar septa are shorter than the other major septa. Septa are thin, or very slightly dilated locally. Yardarm and rare zigzag carinae are present; in a few specimens, the major septa are weakly crenulate.

During stages when the mean corallite diameter increases from 20 to 34 mm, there are 30 to 43 major septa; minor septa may, or may not, be as numerous. Septal arrangement is usually roughly bilateral, and there is commonly a narrow elongated central tabularial region, from which all, or most of the major septa are withdrawn. Typically, a shortened cardinal septum is identifiable at one end of this poorly defined plane of symmetry, although an open, or otherwise well defined cardinal fossula is normally not developed. Septal morphology is extremely variable. Yardarm and zigzag carinae may, or may not, be present, and in some specimens, septa are remarkably crenulate.

In late stages of growth, when the mean corallite diameter is 35 mm or more, there are 35 to 49 major septa. In addition to the variation expressed in preceding stages, the major septa may degenerate and be interrupted by presepiments. One large specimen (GSC 91309) has two alar fossulae as well as a cardinal fossula.

The dissepimentarium in fully grown specimens comprises between 20 and about 30 rows of small, globose dissepiments and larger, elongate dissepiments and presepiments. Inclination of the dissepimentarial surfaces increases toward the axis. Commonly, there is little distinction between the innermost dissepiments and outermost tabulae. Tabulae, which are mostly incomplete, typically form deeply depressed tabularial surfaces, especially as viewed in longitudinal thin sections cut at a high angle to the cardinal-counter plane. Thin sections cut in, or close to the cardinal-counter plane show no modification of the tabulae close to the cardinal septum. Thin sections cut slightly to one side, but roughly parallel to the cardinal-counter plane (McLaren, in McLaren and Norris, 1964, Pl. 6, fig. 1b) show concave tabularial surfaces suspended from adjacent major septa. Normally, 10 to 20 tabulae are counted over a vertical distance of 10 mm. The tabularium is narrow, especially as viewed in thin sections cut at a high angle to the cardinal-counter plane. In late stages of development, when the dissepimentarium is normally at its widest, the ratio of the diameter of the tabularium to that of the whole corallite (Dt/Dc) is commonly (85% of specimens) within the range of 0.14 to 0.30, and is not known to exceed 0.40.

Variation. There is very little variation in the exterior appearance of the corals in the topotypic population. Most specimens closely resemble the specimen illustrated in figure 3 of Plate 4.2; a few, such as the specimen illustrated in figure 6 of the same plate, are more erect. Variations expressed in longitudinal thin sections and in transverse thin sections of early stages (corallite diameter <20 mm) are not significant either. In contrast, transverse thin sections of adult stages reveal a variety of morphologies, which may be grouped into non-genetic formae.

Forma *alpha.* Septa straight to slightly, or moderately crenulate; major septa fully developed; minor septa variable – either complete, discontinuous, or strongly suppressed. Yardarm and zigzag carinae abundant. 10 per cent of the population, including the holotype (Pl. 4.2, figs. 1, 4), belong to this forma.

Forma *beta.* Septa weakly to moderately crenulate; major and minor septa fully developed. Weak sclerenchymal deposits present in tabularium. Yardarm carinae abundant; zigzag carinae also present. 17 per cent of the population, including GSC 91309, 91323 (Pl. 4.3, figs. 2-4), belong to this form.

Forma *gamma.* Septa crenulate in tabularium; major septa fully developed; minor septa mostly fully developed. Sclerenchyme absent from tabularium. Yardarm carinae abundant. 13 per cent of the population, including GSC 91310, 91311 (Pl. 4.4, figs. 3-6), belong to this forma.

Forma *delta.* Septa crenulate in tabularium; major and minor septa fully developed. Few yardarm carinae; zigzag carinae abundant. Seven per cent of the population, including GSC 91324, 91325 (Pl. 4.4, figs. 1, 2, 7; Pl. 4.5, figs. 2, 6), belong to this forma.

Forma *epsilon.* Septa strongly crenulate in tabularium; major septa mostly continuous; minor septa discontinuous. Yardarm carinae rare; zigzag carinae common. 13 per cent of the population, including GSC 91312, 91313 (Pl. 4.5, figs. 1, 3-5), belong to this forma.

Forma *zeta*. Both orders of septa strongly crenulate; major septa locally discontinuous; minor septa commonly reduced, or discontinuous. True carinae rare. 40 per cent of the population, including GSC 91314-91320, 91326, 91327 (Pl. 4.6, figs. 1-8; Pl. 4.7, figs. 1-4; Pl. 4.8, figs. 1-7; Pl. 4.9, figs. 1-5), belong to this forma.

LOCALITY REGISTER

GSC locality 31001. Horn Plateau Formation, presumed reef flank macrofacies, presumed Middle *varcus* Zone, Givetian ("base of poor exposure, or slumped block"). Type Horn Plateau outcrop ("circular hill, northeast of Horn Mountain"), 4.4 km west of the southwestern tip of Fawn Lake, southwestern District of Mackenzie; lat. 62°08'N, long. 117°41.5'W ("62°08.2'N, 117°39'W"). Collected by A.W. Norris, 1957. Fauna includes:

Rhytidolasma boreale (McLaren)
Leptagonia (?) *rhomboidalis* sensu Norris in McLaren and Norris, 1964
Pholidostrophia (?) sp.
Eoschuchertella sp.
Longispina whittakeri Norris
Spinulicosta sp.
Hypothyridina sp.
Spinatrypa (*S.*) *hornensis* Norris
Ambocoelia sp. cf. *A. umbonata* Conrad sensu Norris in McLaren and Norris, 1964
Athyris aquilonius Norris
Eleutherokomma (?) *implana* Norris

GSC locality C-41724. Horn Plateau Formation, reef flank macrofacies (Vopni and Lerbekmo, 1972a, Fig. 6; 1972b, p. 506-510); Middle *varcus* Zone, Givetian. 294 m on a bearing of 57° from Vopni's centre point of the type outcrop, 4.4 km west of the southwestern tip of Fawn Lake, southwestern District of Mackenzie; lat. 62°08'N, long. 117°41.5'W. Collected by A.E.H. Pedder, 1987. Fauna includes:

Pachyfavosites alpenensis calveri (Swann)
Thamnopora sp.
Aulocystis sp.
Lythophyllum sp.
Zelophyllia sp.
Dialeptophyllum vopnii Pedder
Siphonophrentis sp.
Rhytidolasma boreale (McLaren)
Cylindrophyllum gruense McLaren
Fenestrate bryozoan
Schizophoria fascicostella Norris
Sphenophragmus sp. cf. *S. nanus* Imbrie
Leptagonia (?) *rhomboidalis* sensu Norris in McLaren and Norris, 1964
Eoschuchertella sp.
Spinulicosta sp.
Devonoproductus (?) sp. indet.
Productoid brachiopod
Hypothyridina sp.
Leiorhynchus (?) *matonabbee* Norris
Desquamatia sp.
Spinatrypa (*S.*) *hornensis* Norris
Athyris aquilonius Norris
A. (?) sp. narrow form
Eleutherokomma (?) *implana* Norris
Cyrtina sp.
Cranaena sp.
C. (?) *cryptonelloides* Norris
Smooth brachiopods (two forms)
Straparollus (*S.*) sp.
Conocardium sp.
Actinopteria sp.
Trilobite fragments
Ozarkodina brevis (Bischoff and Ziegler)

GSC locality C-41726. Horn Plateau Formation, reef flank macrofacies (Vopni and Lerbekmo, 1972a, Fig. 6; 1972b, p. 506-510); Middle *varcus* Zone, Givetian. 300 m on a bearing of 99° from Vopni's centre point of the type outcrop, 4.4 km west of the southwestern tip of Fawn Lake, southwestern District of Mackenzie; lat. 62°08'N, long. 117°41.5'W. Collected by A.E.H. Pedder, 1987. Fauna includes:

Pachyfavosites alpenensis calveri (Swann)
Thamnopora sp.
Alveolitella sp.
Aulocystis sp.
Cystiphylloides sp.
Tabulophyllum sp.
Rhytidolasma boreale (McLaren)
Fenestrate bryozoans
Sphenophragmus sp. cf. *S. nanus* Imbrie
Leptagonia (?) *rhomboidalis* sensu Norris in McLaren and Norris, 1964, indet.
Productoid brachiopod
Gypidula sp.
Devonogypa sp.
Desquamatia sp.
Spinatrypa (*S.*) *hornensis* Norris
S. (*Isospinatrypa*) sp. indet.
Euomphalid gastropod
Conocardium sp.
Actinopteria sp.
Dechenella (*Basidechenella*) sp. of Norris in McLaren and Norris, 1964

GSC locality C-41728. Horn Plateau Formation, reef flank macrofacies (Vopni and Lerbekmo, 1972a, Fig. 6; 1972b, p. 506-510); Middle *varcus* Zone, Givetian. 340 m on a bearing of 128° from Vopni's centre point of the type outcrop, 4.4 km west of the southwestern tip of Fawn Lake, southwestern District of Mackenzie; lat. 62°08'N, long. 117°41.5'W. Collected by A.E.H. Pedder, 1987. Fauna includes:

Thamnopora sp.
Neospongophylloides sp. nov. (= *Sinospongophyllum* sp. cf. *S. planotabulatum* sensu McLaren in McLaren and Norris, 1964)
Cyathophyllum sp.
Rhytidolasma boreale (McLaren)
Schizophoria fascicostella Norris
Desquamatia sp.
Athyris aquilonius Norris
Cranaena (?) *cryptonelloides* Norris
Actinopteria sp.

GSC locality C-41732. Ludlowville Formation, Centerfield Limestone Member, 0.15-0.3 m above the base of the formation and member; Lower *varcus* Zone, Givetian (Sparling, 1985, Fig. 1). Browns Creek, 0.3 km north of York Road and 0.1 km west of the trestle for the Genesee and Wyoming railroad tracks, York, Geneseo 7.5' Quadrangle, Livingston County, New York. This is bed G of Oliver and Klapper, 1981, p. 25, Stop 8. Collected by A.E.H. Pedder, 1981. Fauna includes:

Heliophyllum halli Milne Edwards and Haime

GSC locality C-41733. Ludlowville Formation, Centerfield Limestone Member, 0.6-0.9 m above base of formation and member; Lower *varcus* Zone, Givetian (Sparling, 1985, Fig. 1). Browns Creek, 0.3 km north of York Road and 0.1 km west of the trestle for the Genesee and Wyoming railroad tracks, York, Geneseo 7.5' Quadrangle, Livingston County, New York. This is bed I of Oliver and Klapper, 1981, p. 25, Stop 8. Collected by A.E.H. Pedder, 1981. Fauna includes:

Heliophyllum halli Milne Edwards and Haime

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P. Johnston, Tyrrell Museum, identified *Actinoptera* sp. in the sample from GSC locality C-41724. F. Tourneur, Forschungs-Institut Senckenberg, identified *Pachyfavosites alpenensis calveri* in the same sample. All of the conodonts listed in the locality register were identified by T.T. Uyeno, Geological Survey of Canada. W.A. Oliver, Jr., United States Geological Survey, suggested improvements to the original manuscript. R.D. Mitchie assisted in the preparation of the thin sections. B.C. Rutley and W.B. Sharman provided all of the photographic prints used, except those of the holotype of *Rhytidolasma boreale*, which were provided by T.T. Bolton.

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PLATES 4.1 to 4.9

PLATE 4.1

All figures enlarged x2. All specimens from the Centerfield Limestone on Browns Creek, Livingston County, New York.

Heliophyllum halli halli (Milne Edwards and Haime)

Figures 1, 11. Longitudinal and transverse thin sections of a specimen that lost the axial dilation of its septa at an early stage, GSC 91303, GSC locality C-41732.

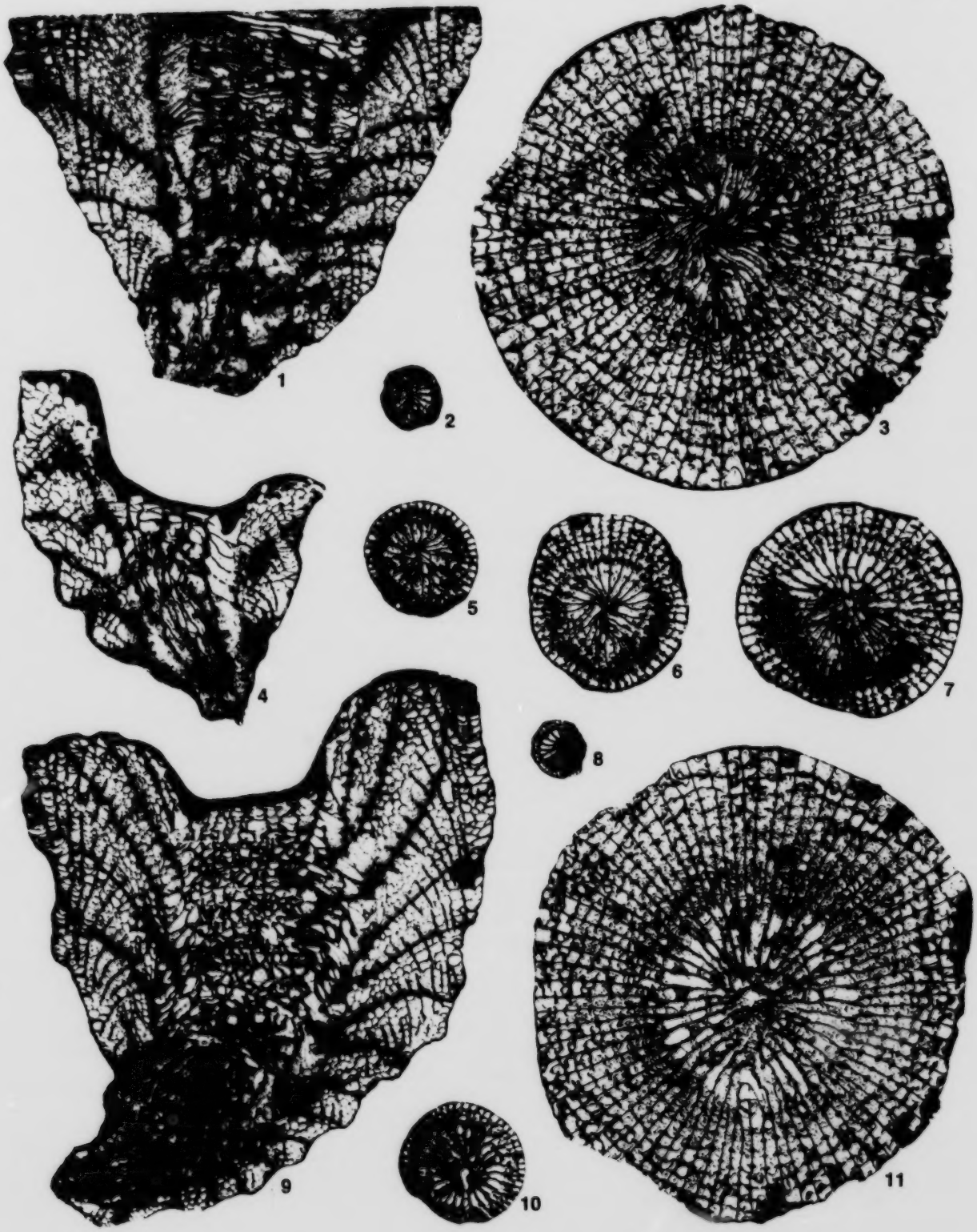
Figures 2, 5-7. Series of transverse thin sections through early stages of a typical specimen with axially dilated septa, GSC 91306, GSC locality C-41733.

Figure 3. Transverse thin section of a specimen which retained axial dilation of its septa until a mature stage, GSC 91305, GSC locality C-41733.

Figure 4. Longitudinal thin section of a specimen that died young, GSC 91304, GSC locality C-41732.

Figures 8, 10. Transverse thin sections through early stages of a specimen with axially dilated septa, GSC 91307, GSC locality C-41733.

Figure 9. Longitudinal thin section of a typical specimen that died soon after reaching maturity, GSC 91308, GSC locality C-41733.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11

PLATE 4.2

Figures of the exteriors are natural size; interior thin sections enlarged x2.5.
All specimens from the flank of the type Horn Plateau Reef.

Rhytidolasma boreale (McLaren)

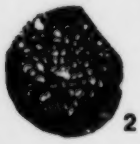
Figures 1, 4. Alpha forma, longitudinal and transverse thin sections, holotype, GSC 16483, GSC locality 31001.

Figures 2, 5. Transverse thin sections of a specimen too immature to be assigned to a forma, GSC 91321, GSC locality C-41724.

Figure 3. Exterior of a typical unsectioned specimen, GSC 91322, GSC locality C-41724.

Figure 6. Exterior of an unusually straight specimen; thin sections show this specimen to be a zeta forma, GSC 91314, GSC locality C-41724.

1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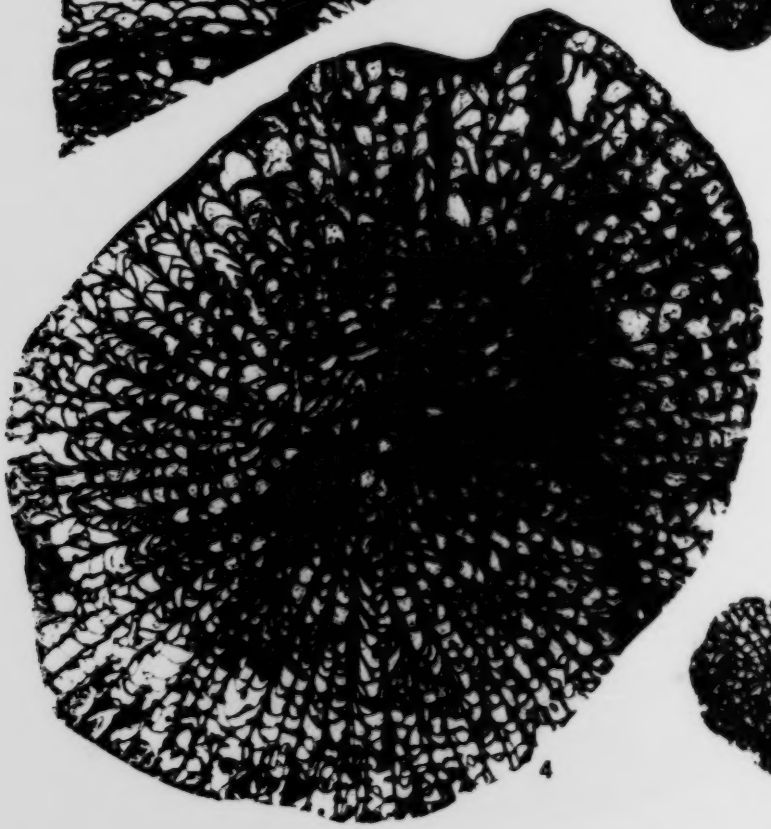
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5

6

PLATE 4.3

Figure of the exterior enlarged x5; interior thin sections enlarged x2.5.
All specimens from the flank of the type Horn Plateau Reef.

Rhytidolasma boreale (McLaren)

Figure 1. Part of the exterior of a typical specimen; thin sections show this specimen to be a zeta forma, GSC 91315, GSC locality C-41724.

Figures 2, 3. Beta forma, longitudinal and transverse thin sections, GSC 91309, GSC locality C-41724.

Figure 4. Beta forma, transverse thin sections of an early stage, GSC 91323, GSC locality C-41726.

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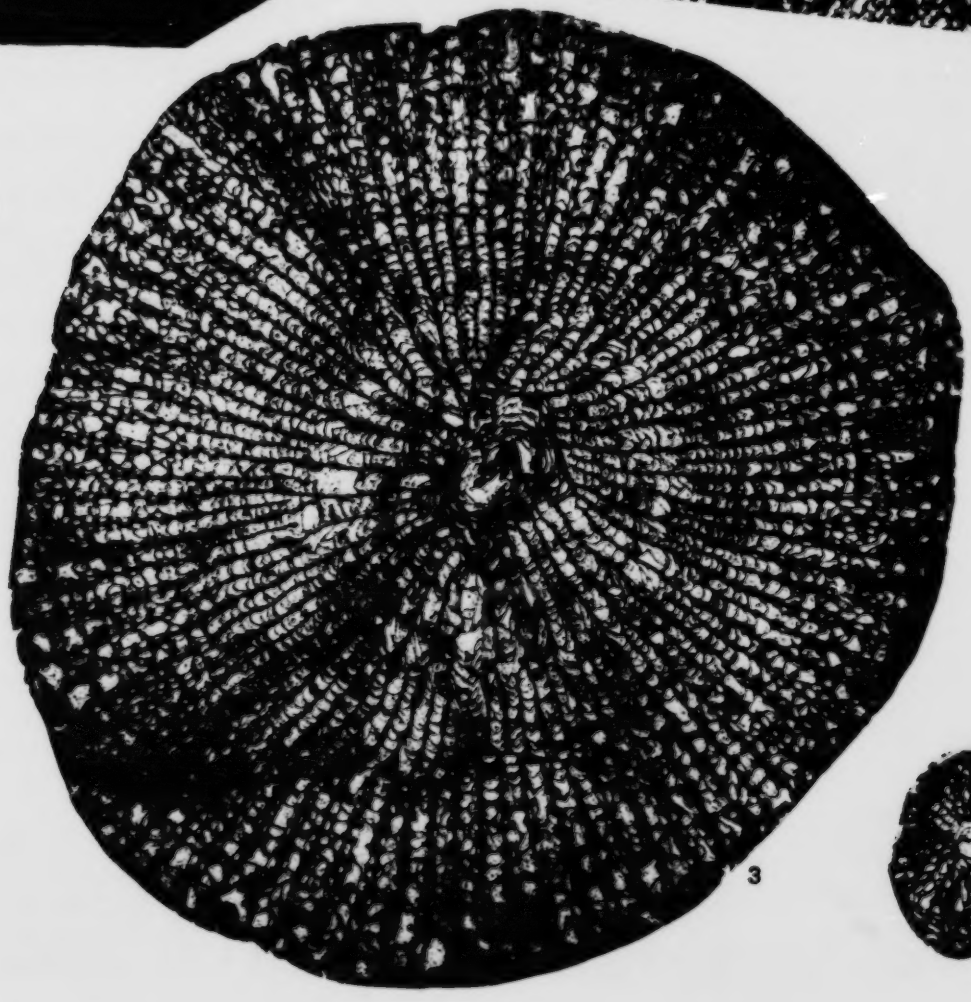

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PLATE 4.4

All figures enlarged x2.5.
All specimens from the flank of the type Horn Plateau Reef.

Rhytidolasma boreale (McLaren)

Figures 1, 2, 7. Delta forma, longitudinal thin section and transverse thin sections through mature and early stages, GSC 91324, GSC locality C-41726.

Figures 3, 5. Gamma forma, transverse and longitudinal thin sections, GSC 91310, GSC locality C-41724.

Figures 4, 6. Gamma forma, two transverse thin sections of a damaged specimen, GSC 91311, GSC locality C-41724.

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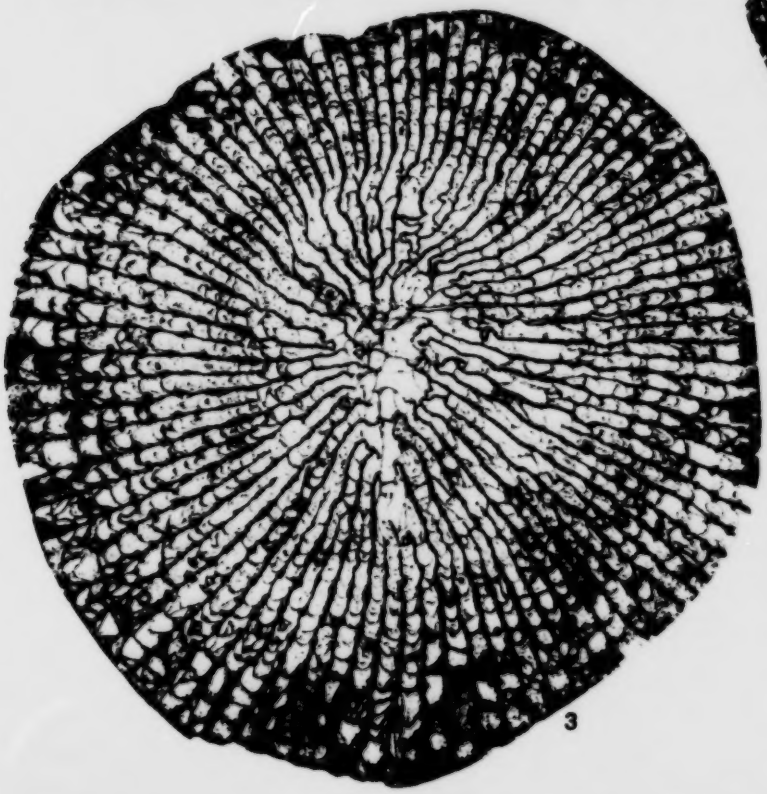
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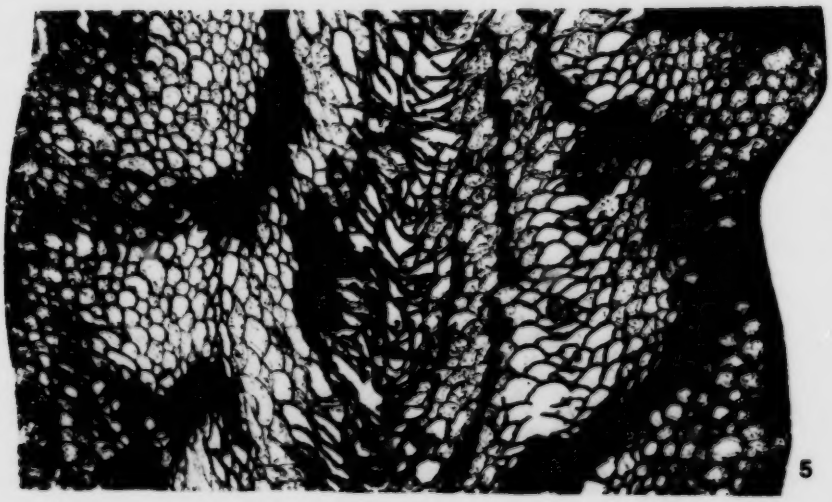
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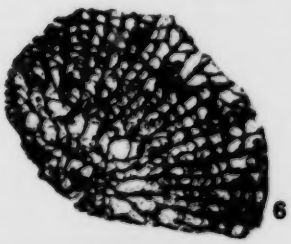
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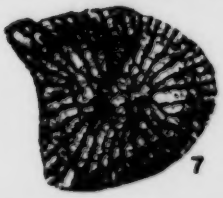
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PLATE 4.5

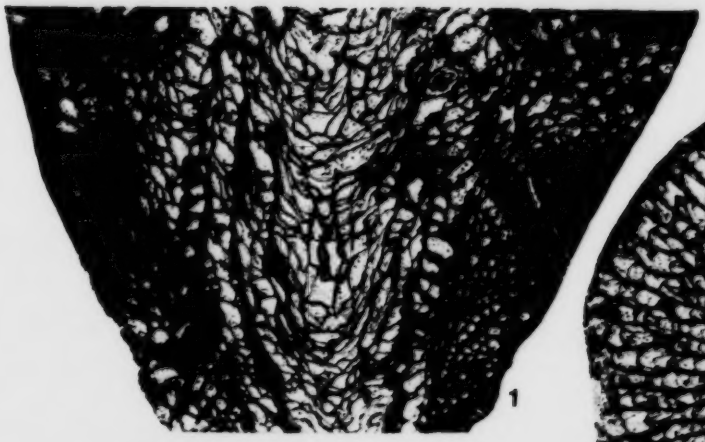
All figures enlarged x2.5.
All specimens from the flank of the type Horn Plateau Reef.

Rhytidolasma boreale (McLaren)

Figures 1, 5. Epsilon forma, longitudinal thin section and (left side) a transverse thin section through an early stage, GSC 91312, GSC locality C-41724.

Figures 2, 6. Delta forma, transverse and longitudinal thin sections, GSC 91325, GSC locality C-41726.

Figures 3, 4. Epsilon forma, longitudinal and transverse thin sections, GSC 91313, GSC locality C-41724.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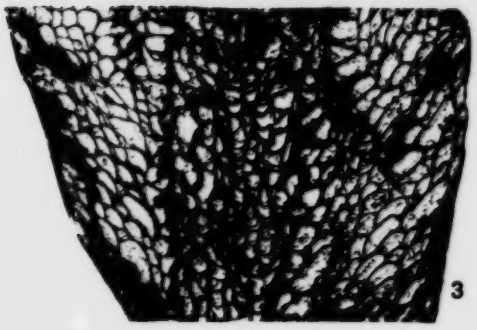
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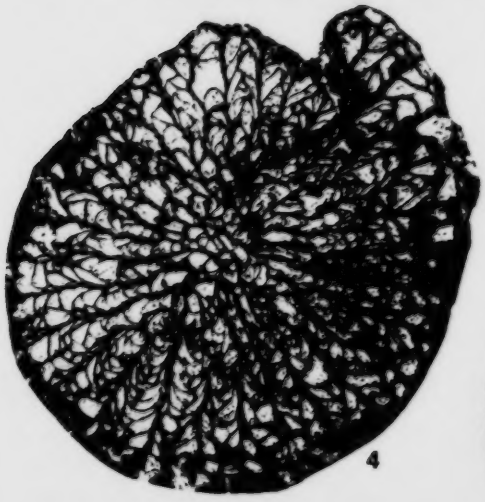
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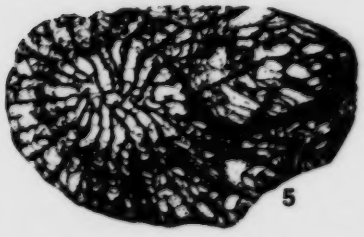
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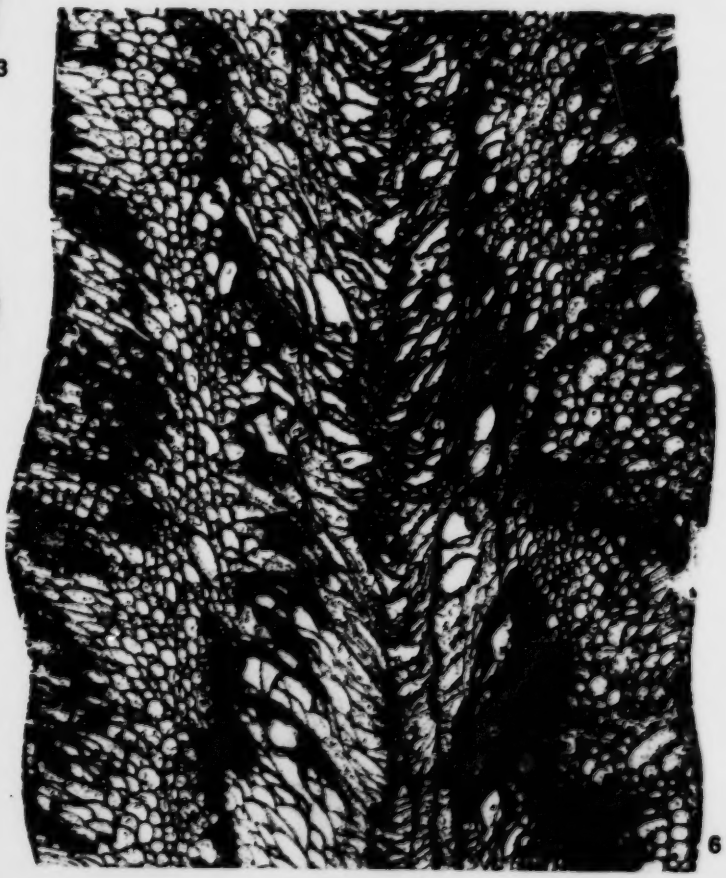
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PLATE 4.6

All figures enlarged x2.5.
All specimens from the flank of the type Horn Plateau Reef.

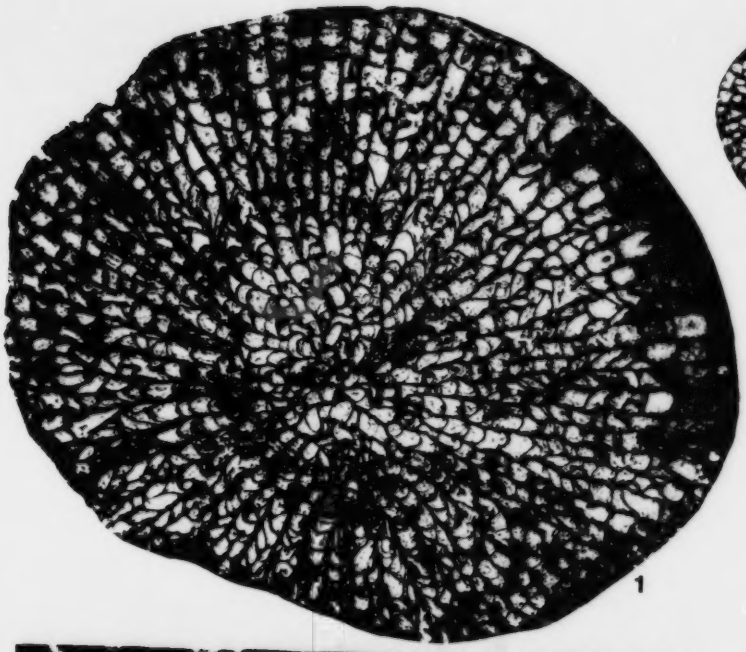
Rhytidolasma boreale (McLaren)

Figures 1, 7. Zeta forma, transverse and longitudinal thin sections, GSC 91316, GSC locality C-41724.

Figures 2-4. Zeta forma, two transverse thin sections through early stages and a longitudinal thin section, GSC 91317, GSC locality C-41724.

Figure 5. Zeta forma, transverse thin section, GSC 91318, GSC locality C-41724.

Figures 6, 8. Zeta forma, transverse and longitudinal thin sections, GSC 91319, GSC locality C-41724.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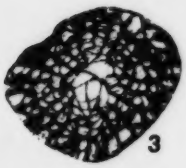
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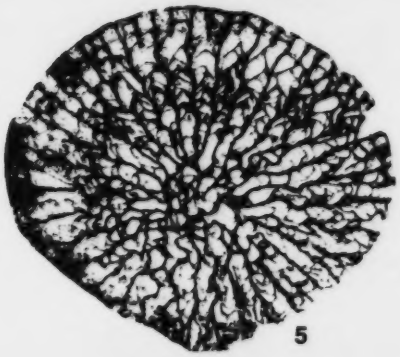
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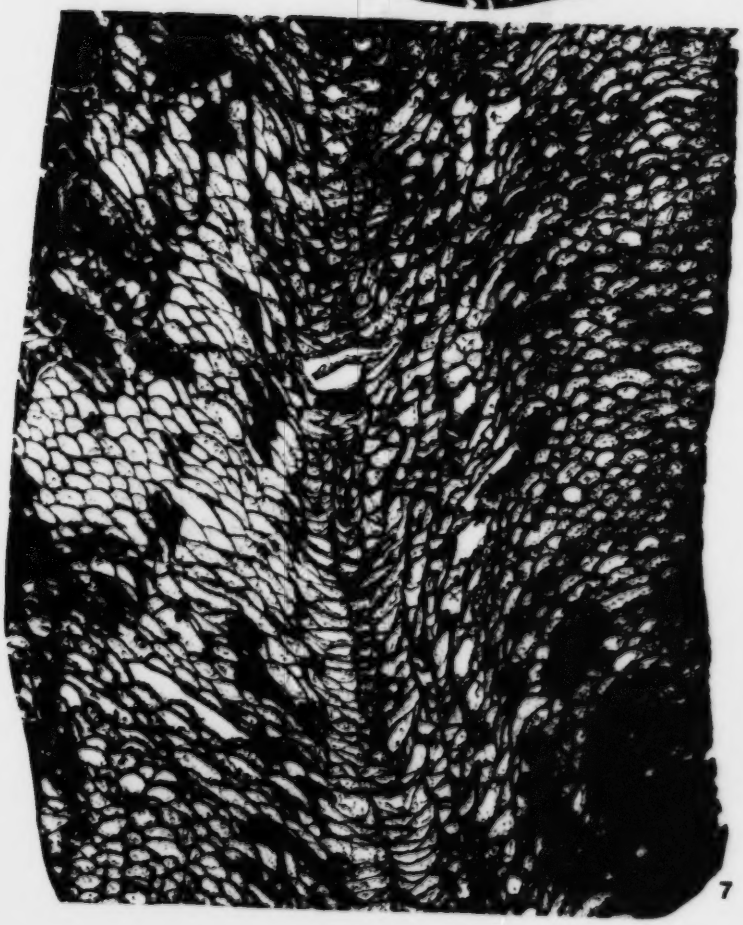
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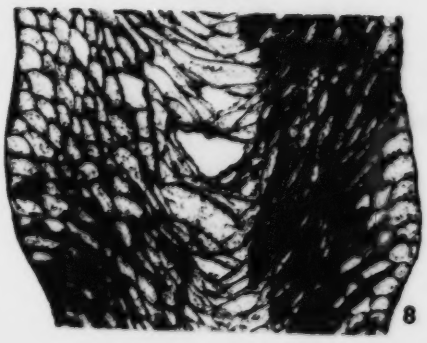
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PLATE 4.7

All figures enlarged x2.5.
All specimens from the flank of the type Horn Plateau Reef.

Rhytidolasma boreale (McLaren)

Figures 1-3. Zeta forma, two transverse thin sections and a longitudinal thin section of a large specimen, GSC 91320, GSC locality C-41724.

Figure 4. Zeta forma, longitudinal thin section through a small specimen that increased in diameter slowly, GSC 91318, GSC locality C-41724.

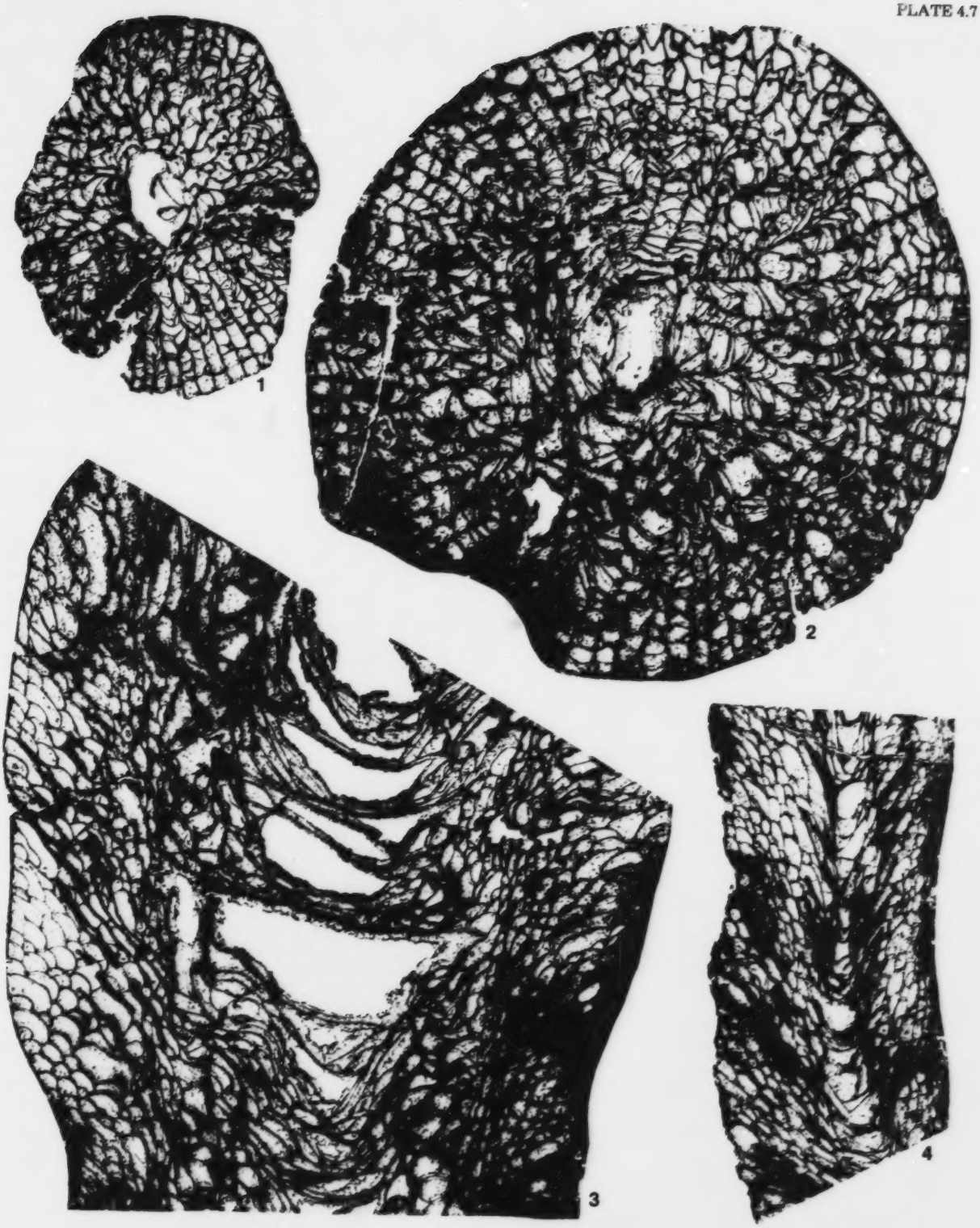
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PLATE 4.8

All figures enlarged x2.5.
All specimens from the flank of the type Horn Plateau Reef.

Rhytidolasma boreale (McLaren)

Figure 1. Zeta forma, transverse thin section across the proximal end of the specimen depicted in figure 6 of Plate 4.2, GSC 91314, GSC locality C-41724.

Figure 2. Zeta forma, longitudinal thin section of a large specimen, GSC 91315, GSC locality C-41724.

Figure 3. Zeta forma, transverse thin section through an early stage, GSC 91320, GSC locality C-41724.

Figure 4. Zeta forma, transversve thin section through an early stage, GSC 91318, GSC locality C-41724.

Figures 5-7. Zeta forma, transverse thin sections through late and early stages, and a longitudinal thin section of a typical specimen, GSC 91326, GSC locality C-41728.

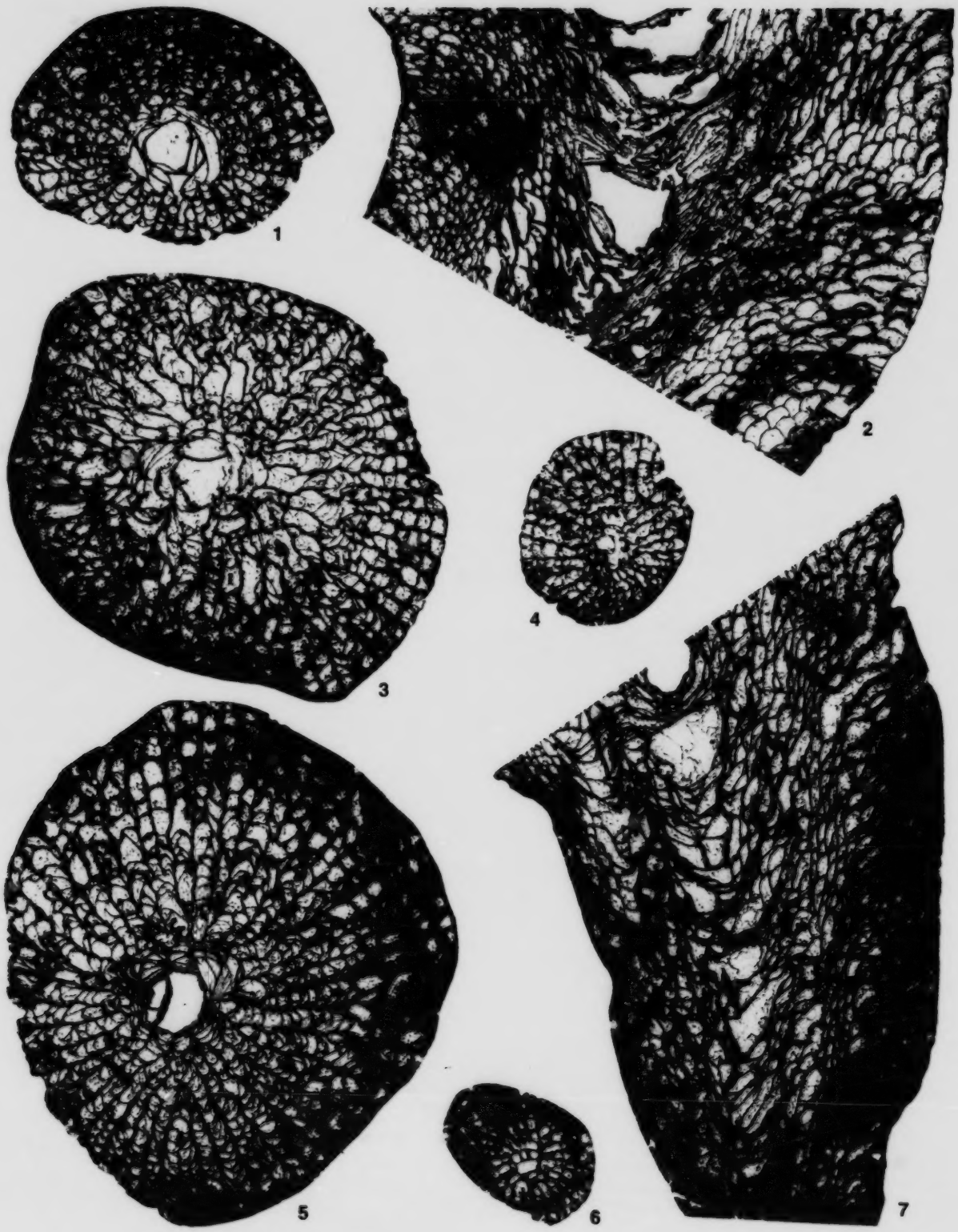
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PLATE 4.9

All figures enlarged x2.5.
All specimens from the flank of the type Horn Plateau Reef.

Rhytidolasma boreale (McLaren)

Figure 1. Zeta forma, longitudinal thin section of the specimen depicted in figure 6 of Plate 2, GSC 91314, GSC locality C-41724.

Figures 2, 5. Zeta forma, transverse sections of a large specimen with presepiments, GSC 91315, GSC locality C-41724.

Figures 3, 4. Zeta forma, transverse and longitudinal thin sections of a specimen with unusually numerous septa, GSC 91327, GSC locality C-41728.

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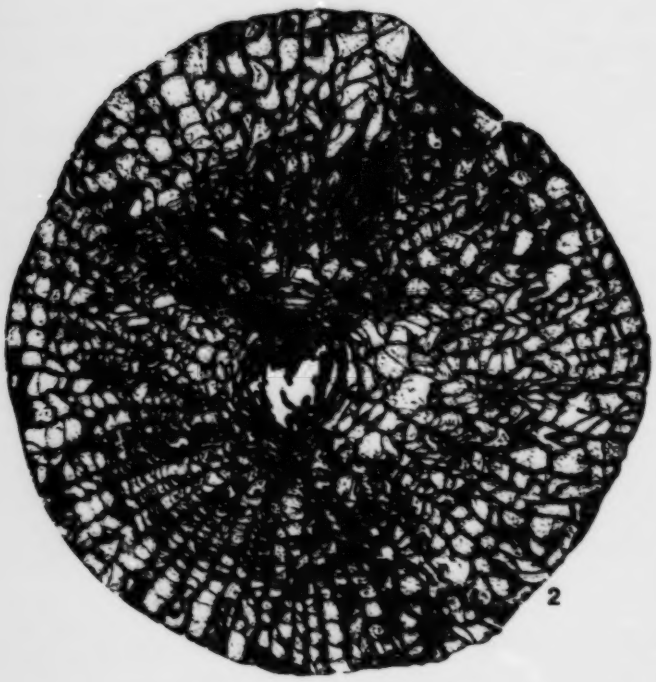
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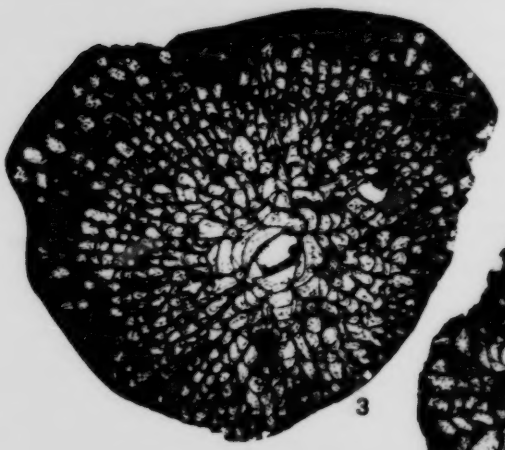
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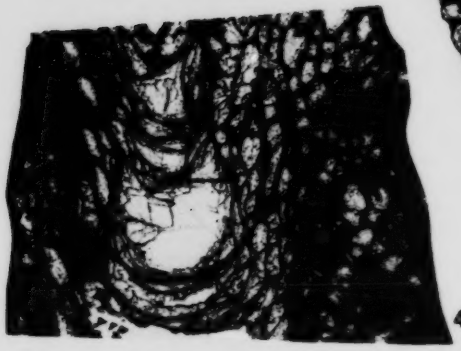
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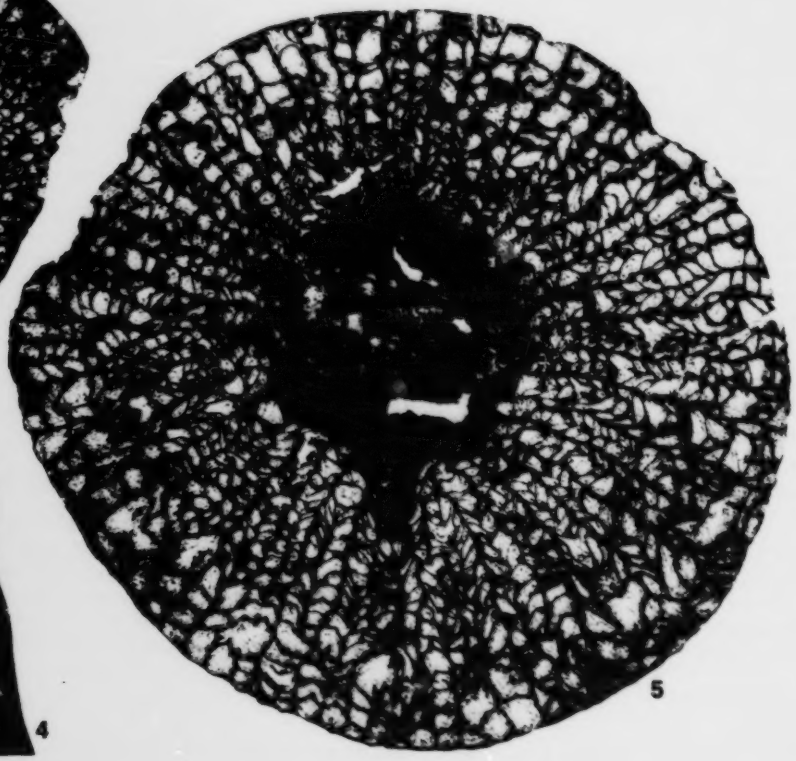
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PALYNOLOGY AND STRATIGRAPHY OF THE LOWER CARBONIFEROUS HORTON GROUP, NOVA SCOTIA

J. Utting[1], J.D. Keppie[2], and P.S. Giles[2]

Utting, J., Keppie, J.D., and Giles. P.S., Palynology and stratigraphy of the Lower Carboniferous Horton Group, Nova Scotia. In Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 396, p. 117-143, 1989.

Abstract

Four informal palynological assemblage zones and two subzones are recognized in the Tournaisian (Tn_2 and Tn_3) of Nova Scotia, and their probable ages are established by correlation with the spore zones of Western Europe. Assemblages from the lower member and lower part of the middle member of the Horton Bluff Formation are late Tn_2 to early Tn_3 in age; those from the upper middle member and the upper member of the Horton Bluff Formation and the Cheverie Formation are early to mid Tn_3; and those from the Wilkie Brook and Coldstream formations are late Tn_3. Beds of part of an unnamed formation near Lakevale, Antigonish Basin, may be early to mid Tn_2, slightly older than the Horton Bluff type section. The Lower Windsor Group, which overlies the Horton Group, is Viséan (V_2 to early V_3).

The Horton Group is expanded to include the Wilkie Brook Formation. The hiatus between this modified Horton Group and the Windsor Group is believed to represent part of the early (V_1) to middle (V_2) Viséan. There may not be a hiatus in some places, however, but the beds representing this time interval are barren of palynomorphs.

Tournaisian assemblages from the Albert Formation (New Brunswick), the lower member and the lower part of the middle member of the Horton Bluff Formation (Windsor Basin), the oil shales of the Rights River Formation (Antigonish Basin), and part of the Diamond Brook Formation (Cumberland Basin) are alike.

One new species, *Spelaeotriletes cabotii*, is proposed, and one, *Leiotriletes* sp. A, is described, but not named because too few specimens were found. Specimens of *Emphanisporites rotatus* McGregor are described and discussed. Selected reworked(?) acritarchs are illustrated.

The Thermal Alteration Index of the Horton Group throughout the study area is low to medium (from 2- to 3+). This suggests that there was a potential for liquid hydrocarbon generation in the areas with low thermal maturity (e.g., southwest Windsor Basin and northern Antigonish Basin), but in areas where values are higher (3 to 3+), the potential was for condensate and dry gas generation.

Résumé

Quatre zones d'assemblage palynologique informelles et deux sous-zones ont été localisées dans le Tournaisien (Tn_2 et Tn_3) de la Nouvelle-Écosse et leur âge probable a été déterminé par corrélation avec les zones à spores de l'Europe de l'Ouest. Les assemblages du membre inférieur et de la partie inférieure du membre intermédiaire de la formation de Horton Bluff datent du Tn_2 supérieur au Tn_3 inférieur; les assemblages de la partie supérieure du membre intermédiaire et du membre supérieur de la formation de Horton Bluff et de la formation de Cheverie remontent au Tn_3 inférieur à moyen; et ceux des formations de Wilkie Brook et Coldstream remontent au Tn_3 supérieur. Les couches d'une partie d'une formation non désignée près de Lakevale dans le bassin d'Antigonish pourraient remonter au Tn_2 inférieur à moyen, soit être légèrement plus anciennes que le stratotype de Horton Bluff. La partie inférieure du groupe de Windsor qui repose sur le groupe de Horton remonte au Viséen (de V_2 à V_3 inférieur).

Le groupe de Horton a été étendu pour inclure la formation de Wilkie Brook. La lacune stratigraphique entre le groupe de Horton modifié et le groupe de Windsor devrait représenter une partie du Viséen inférieur (V_1) à moyen (V_2). Il se peut, cependant, qu'aucune lacune ne se trouve à certains endroits mais les couches représentant cette intervalle temporel ne contiennent pas de palynomorphes.

Les assemblages tournaisiens de la formation d'Albert (Nouveau-Brunswick), le membre inférieur et la partie inférieure du membre intermédiaire de la formation de Horton Bluff (bassin de Windsor), les schistes bitumineux de la formation de Rights River (bassin d'Antigonish) et une partie de la formation de Diamond Brook (bassin de Cumberland) sont semblables.

Une nouvelle espèce, *Spelaeotriletes cabotii*, est proposée et une autre, *Leiotriletes* sp. A, est décrite mais non désignée étant donné la rareté des spécimens trouvés. Les spécimens d'*Emphanisporites rotatus* McGregor sont décrits et traités. Une sélection d'acritarches remaniés (?) est illustré.

Dans la zone à l'étude, l'indice d'altération thermique de groupe de Horton est de faible à moyen (2- et 3+). Ces valeurs semblent indiquer qu'il existe un potentiel de formation d'hydrocarbures liquides dans les zones à faible maturité thermique (p. ex. dans le sud-ouest du bassin de Windsor et le nord du bassin d'Antigonish); cependant, dans les zones où les valeurs sont plus élevées (de 3 à 3+), ce serait plutôt du condensat et du gaz sec qui se seraient formés.

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INTRODUCTION

The presence of oil shales in lacustrine and fluviatile rocks of the Lower Carboniferous (Tournaisian) Horton Group and its equivalents in Atlantic Canada, has generated economic interest for many years. The complex stratigraphy of the beds, due to rapid lateral facies changes, incomplete sections, and insufficient biostratigraphic data, has hindered petroleum and mineral exploration. The stratigraphic relationship of the Horton Group to the overlying marine Windsor Group is of special interest due to the discovery of uranium in both groups and lead and zinc deposits in the lowermost Windsor, near the contact of the groups.

An improved understanding of the stratigraphy of these rocks could prove to be of value in oil and gas exploration; it is already known that liquid hydrocarbons occur in some strata (e.g., the oil shales of the Albert Formation of New Brunswick [Macauley, Ball and Powell, 1984], and the Rights River Formation of Antigonish, Nova Scotia [Macauley and Ball, 1984]).

The type sections for both the Horton and Windsor groups occur in the vicinity of the estuary of the Avon River, Windsor, Nova Scotia (Bell, 1929, 1960). Bell (1960) subdivided the Horton Group into two formations: the Horton Bluff and the overlying Cheverie Formation (Fig. 5.1). The Horton Bluff Formation consists of three members: a 200 m thick basal or lower member of conglomerate, sandstone and shale; a 600 to 1100 m thick middle member, made up mainly of shale interbedded with some siltstone and sandstone; and a 170 m thick upper member composed predominantly of sandstone and shale with some layers of argillaceous dolomite and quartzite. The Cheverie Formation consists of at least 200 m of interbedded conglomerate, sandstone, siltstone and shale. The overlying Windsor Group (Fig. 5.1) consists of at least 700 m of interbedded limestone, evaporites, sandstone and shale.

The basal contact of the Horton Bluff Formation with the Cambro-Ordovician Meguma Group is an angular unconformity, or a nonconformity where it lies upon Devonian granites (Bell, 1929, 1960). The contact between the Horton Bluff and Cheverie formations is not well exposed in the type area. Bell (1929) suggested that it is disconformable, but Boyle (1963) discovered an angular unconformity between the two formations just to the north at Walton. Bell (1929, 1960) and Boyle (1963) described the contact between the Windsor and Horton groups as conformable or slightly disconformable between Cheverie Point and Walton. However, two of us (Keppie and Utting) discovered an angular unconformity at the base of the marine quartzite of the Windsor Group on the headland just north of Cheverie Point.

Bell (1960) assigned the Horton Group a Tournaisian age on the basis of its plant fossils, and suggested that the Cheverie Formation was late Tournaisian. Previously, Bell (1929) had assigned the lower part of the Windsor Group (zones A and B) to the middle Viséan based on macrofauna, but he subsequently changed this to early Viséan without stating his reasons (Bell, 1960). The original middle Viséan age was supported by conodont evidence (von Bitter and Austin, 1984), whereas Mamet (1970) suggested a late Viséan age based on foraminifers. Miospores indicate a middle Viséan (V_2) to possibly early late Viséan (V_3) age for the Windsor Group (Utting, 1987a).

Most geologists working outside the type area have assigned units lying stratigraphically beneath the Windsor Group and above the "Acadian Unconformity" at the top of

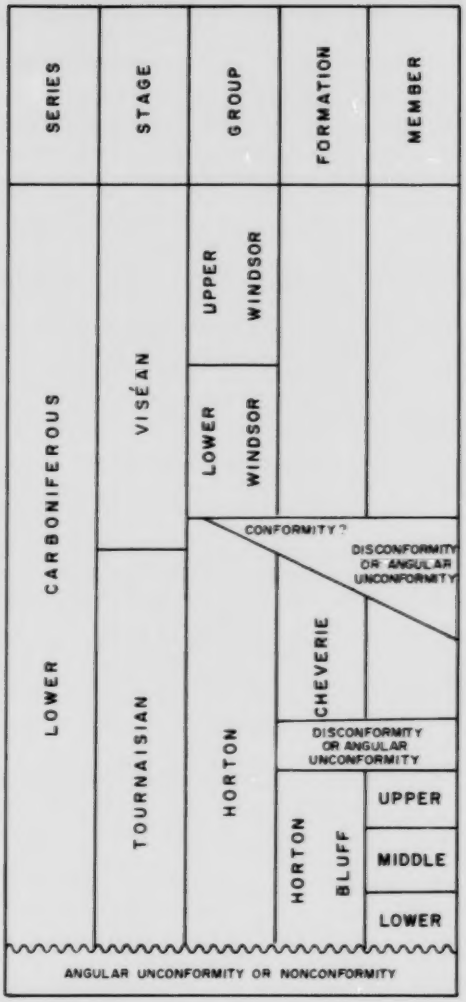


Figure 5.1. *Lithostratigraphic divisions and probable ages of Lower Carboniferous rocks in Nova Scotia. (Modified from Bell, 1929.)*

the lower Devonian, to the Horton Group (e.g., Bell, 1958; Weeks, 1954; Kelley, 1967; Howie and Barss, 1975). This procedure has sometimes been followed without any specific reference to units defined in the type area. Some of these beds are considerably older than those in the type section of the Horton Group, and their inclusion in an expanded definition of the Horton Group would necessitate a formal revision, or the erection of a new unit, neither of which has been done. This practice contravenes the code of the North American Commission on Stratigraphic Nomenclature (1983), and has led to confusion. Detailed stratigraphic comparison with the type sections is particularly important as there are unconformities in the type area, and stratigraphic units exposed elsewhere may correlate partly or wholly with the stratigraphic gaps.

This paper presents a summary of the palynological data available from the type area of the Horton Group at Horton Bluff and Cheverie based on systematic sampling of lithostratigraphically well defined sections (Figs. 5.2, 5.3). Palynological data from sections in other areas

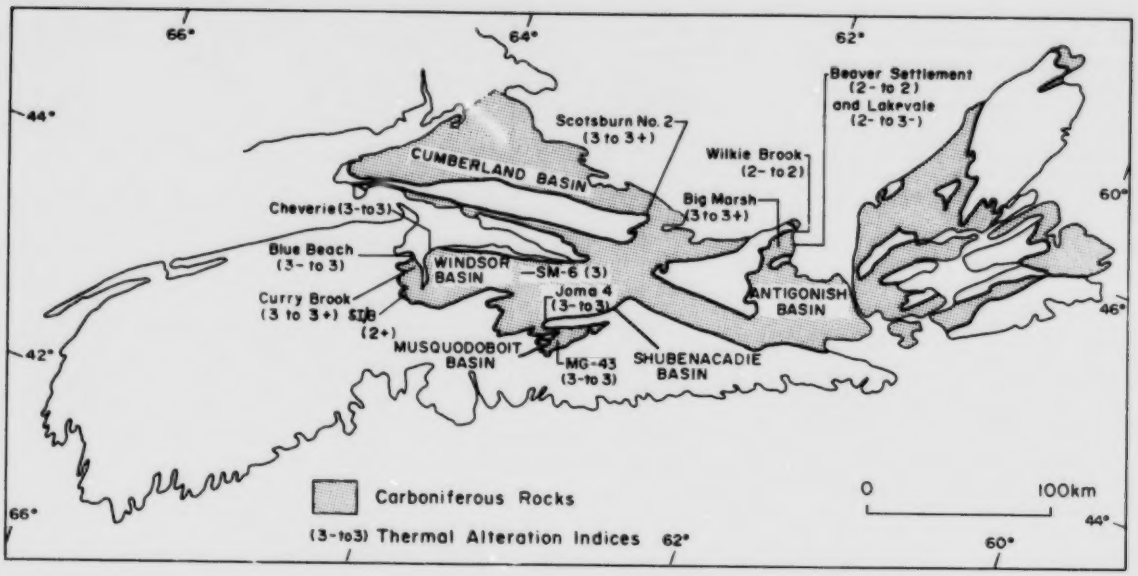


Figure 5.2. *Distribution of Carboniferous rocks, sample localities, and locations of basins from which samples were taken. Thermal Alteration Index values are shown in parentheses.*

(Figs. 5.2, 5.4) are also presented for rocks underlying the Windsor Group, and lithostratigraphic correlations with the type section of the Horton Group are attempted (Fig. 5.5). Details concerning the palynology of the Windsor Group have been given elsewhere (Utting, 1987a), but the assemblages are summarized here because they are critical to understanding the nature of the Horton-Windsor boundary. The palynological data are important in the interpretation of the geological history of the Horton and Windsor groups.

PREVIOUS PALYNOLOGICAL WORK

Hacquebard (1957) published palynological data obtained from one sample of the Horton Bluff Formation and from one sample of beds that he considered to be its lateral equivalent. No precise age determination was possible at the time because few palynological data were available from other Lower Carboniferous localities with good stratigraphic control. Bell (1960) recorded two megaspore species, one from the Horton Bluff Formation and the other from the Cheverie Formation. Playford (1964) studied the spores from one sample of the Horton Bluff Formation, five samples of the Cheverie Formation, and seven samples of the undivided Horton Group, which he believed to be the lateral equivalent of the Horton Bluff Formation. Like Hacquebard, he was unable to make any precise age determinations because of insufficient comparative palynological data. An atlas illustrating spores from the Horton Bluff and Cheverie formations and the Windsor Group was published by Barss in 1967. The ages given in the atlas (Tournaisian for the Horton Group and Viséan for the Windsor Group) were based on those of Bell (1929, 1960). Varma (1969) pointed out the close similarities between spores from the Albert Formation of New Brunswick and those from the Horton Bluff and Cheverie formations. Barss and Hacquebard (in Hacquebard 1972, Fig. 4) summarized the palynological data from the Horton Bluff and Cheverie formations and assigned the assemblages from these two formations to 'spore zone g'. This zone contains *Vallatisporites vallatus* and *Spelaeotriletes pretiosus* and straddles the Tournaisian-Viséan boundary (Barss and Hacquebard, op. cit.). Howie and Barss (1975) also showed the Cheverie Formation to be of late Tournaisian to early Viséan age.

STRATIGRAPHIC SETTING

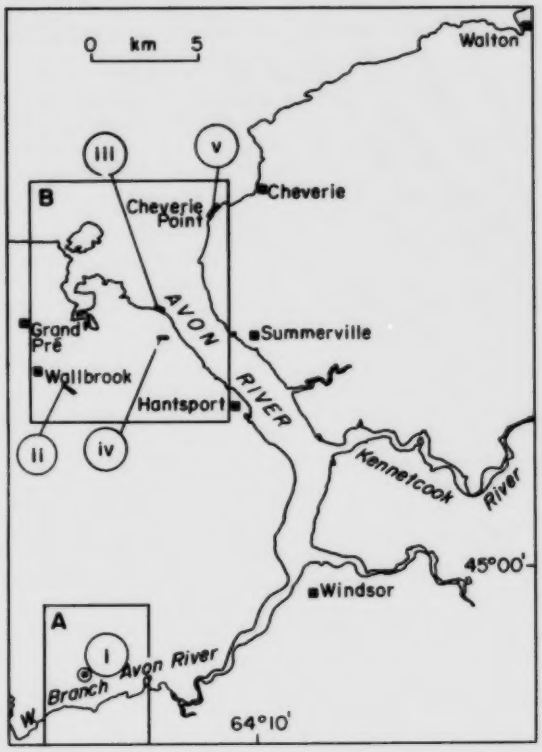
Reliable stratigraphic correlation of beds within the Horton Group is difficult because of lateral facies changes, lack of thick continuous sections, and insufficient biostratigraphic data. In an attempt to provide more biostratigraphic information, samples were collected from strata in the type area of the Horton Group, including the Horton Bluff and Cheverie formations, the Wilkie Brook Formation and beds of uncertain lithostratigraphic correlation.

The lithology of the type sections in the Windsor Basin and other studied sections in the Musquodoboit, Shubenacadie, Cumberland and Antigonish basins is summarized in Figure 5.5. These sections are briefly described in subsequent paragraphs.

Windsor Basin

Horton Group type sections (Figs. 5.2, 5.3, 5.5)

Bell (1929, 1960) described the Horton Group in the Windsor area, but did not propose type sections for the three members of the Horton Bluff Formation (lower, middle and upper). Characteristic rock types were summarized, and a list of selected localities with good exposures were given. Furthermore, the arbitrary nature of boundaries between members was stressed Bell (1960, p. 4). Crosby (1962) mapped the Horton Bluff and Cheverie formations, but did not subdivide the units into members. This was done when the area was mapped by Ferguson (1983) and Moore and Ferguson (1986); these published maps were used by the authors of this paper when determining the field relationships of the palynological samples.



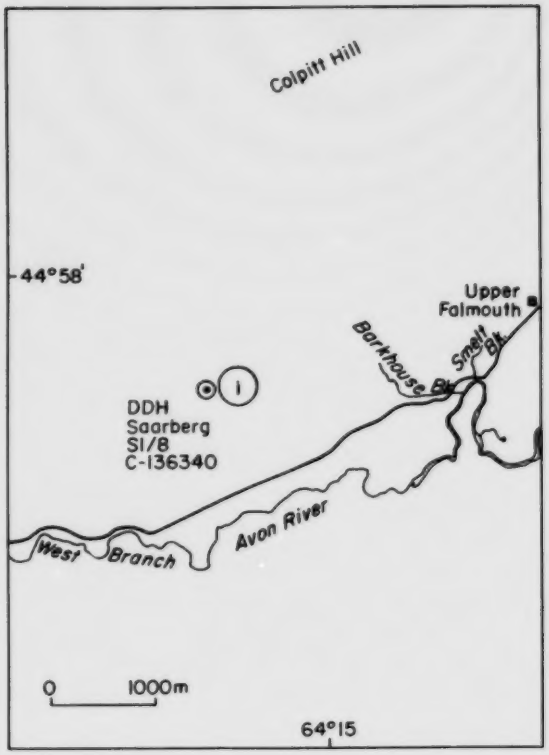


Figure 5.3. *Location of sections in type area of the Horton Bluff and Cheverie formations, Windsor Basin. Rectangles A and B are enlarged in Figures 5.3A and 5.3B.*

Localities i, and ii to v, are shown in Figures 5.3A and 5.3B, respectively, along with GSC locality numbers, e.g. C-136340.

Figure 5.3A

i = Saarberg Interplan Canada Limited SI/8, subsurface core section of lower member, Horton Bluff Formation.

The basal member of the Horton Bluff Formation is about 200 m thick, and consists of a basal breccia overlain by interbedded feldspathic conglomerate, quartzitic sandstone, arenaceous, micaceous shale, and rare, thin coal horizons. Crossbedding and ripple marks are common. The member contains fragmentary plant remains, and has been interpreted as a fluviatile unit (Bell, 1929, 1960). Seventeen samples (GSC locality C-136340, 31.0 m to 108.0 m) were collected for palynological analysis (Figs. 5.2, 5.3Ai, 5.5) from a drill core (Saarberg Interplan Canada Limited SI/8, GSC locality C-136340, lat. 44°57'10"N., long. 64°15'50"W). This core is 119 m long and was drilled approximately perpendicular to the bedding. It was collared about 90 m below the top of the member and penetrated underlying granodiorite at 110 m. A basal arkosic breccia nonconformably overlies the granodiorite, and is in turn overlain mainly by sandstone interbedded with siltstone, shale and a few thin coal horizons. In addition, seventeen samples (from GSC localities C-146247 to C-146250, and C-161401 to C-161413) were collected from the upper part of the member in sections exposed along Curry Brook (Figs. 5.3Bii, 5.5).

The middle member of the Horton Bluff Formation is 600 to 1100 m thick. Bell (1960) divided this member into two units: a lower unit, 200 to 700 m thick, composed essentially of quartzitic sandstone and micaceous, arenaceous shale with some thin siltstone, all containing carbonized comminuted plant debris; and an upper unit, 400 m thick, consisting mainly of shale rich in ostracodes and a few horizons of quartzite, and ferruginous limestone containing paleoniscid fish fragments and *Spirorbis*. Ripple marks and crossbedding are present in the sandstone beds. This middle member is interpreted as a lacustrine or fluviolacustrine deposit (Bell, 1960). Fourteen samples (from GSC localities C-146233 to C-146246) were obtained from the lower part of the middle member in Curry Brook (Figs. 5.3Bii, 5.5). The best exposure of the member occurs in cliffs at Horton Bluff, although this section is believed to represent only the upper unit of the middle member (Bell, 1960). From the syncline below the Avonport Lighthouse westward to the end of the outcrop, thirty-one samples (from GSC localities C-136307 to C-136339) were collected from about 80 m of strata (Figs. 5.2, 5.3Bii, 5.5). The exact stratigraphic position of this section within the upper unit of the middle member is unknown because neither the top nor the bottom of the member is exposed. To partly compensate for this problem, a sample of rock from the middle member (from GSC locality C-97746) was also collected from Hurd Creek just below the base of the upper member (Figs. 5.2, 5.3Biv, 5.5).

The upper member of the Horton Bluff Formation is about 100 m thick, and consists of feldspathic sandstone, conglomerate interbedded with shale, arenaceous shale, quartzite, dolomite, limestone, and ironstone. Plant and paleoniscid fish fragments are found, as well as ostracodes. A quartzitic sandstone marker horizon near the base of the member was formerly quarried for glass sand. This member has been interpreted as a fluviatile deposit (Bell, 1960; MacDonald, 1971). One of the best sections, on Hurd Creek (GSC localities C-97742 to C-97745; Figs. 5.2, 5.3Biv, 5.5), was selected for palynological sampling.

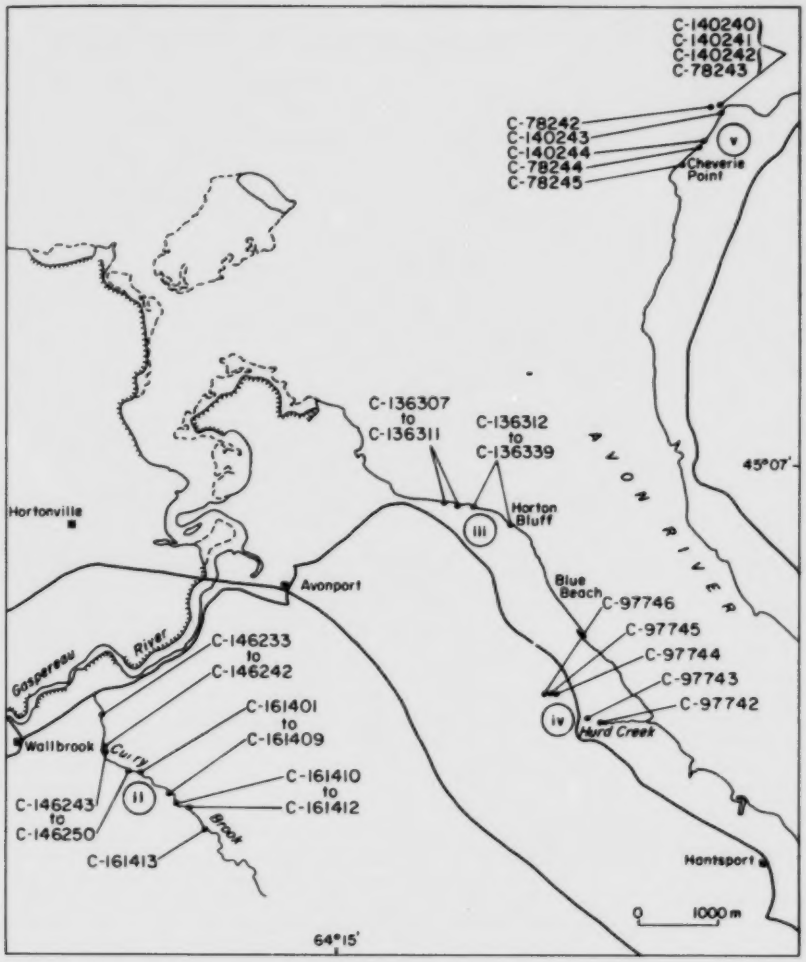


Figure 5.3B

- *ii = Curry Brook section, upper part of lower member and lower part of middle member, Horton Bluff Formation.*
- *iii = Horton Bluff cliff section, upper part of middle member, Horton Bluff Formation (type section).*
- *iv = Hurd Creek section, uppermost part of middle member and upper member, Horton Bluff Formation.*
- *v = Cheverie Point, Cheverie Formation (type section).*

The Cheverie Formation is at least 200 m thick, and consists of interbedded red and brown sandstone, conglomerate, siltstone, shale, mudstone and a few quartzite horizons. It contains plant debris (including sphenopterids), estherioids and rare fish scales. Crossbedding and soil beds containing rootlet casts are common. A fluviatile origin has been inferred for the Cheverie Formation (Bell, 1929, 1960; Freeman, 1972). The type section of the formation between Cheverie Point and White Head (Fig. 5.3Bv) shows a slight angular unconformity rather than a disconformity between the Cheverie Formation and basal marine clastics of the Windsor Group (Fig. 5.1) (cf. Bell, 1960; Boyle, 1963; Freeman, 1972). This may mean that the beds immediately below the contact with the Windsor Group here are older than the youngest beds of the Cheverie Formation elsewhere. Nine samples from GSC localities C-140240 to C-140244, and C-78242 to C-78245 were collected from the best exposed section of the Cheverie Formation, about 200 m (Figs. 5.2, 5.3Bv, 5.5) north of Cheverie Point. The top of the Cheverie Formation is truncated by an angular unconformity below 7 m of fossiliferous marine sandstone, the basal unit of the Windsor Group at this locality. This is, in turn, overlain by the 7 m thick Macumber Formation, a finely bedded limestone lacking macrofossils.

Other sections of the Horton Group (Figs. 5.2, 5.5)

Samples of core from seven drillholes along the northern side of the Windsor Basin were obtained for palynological analysis. All the drillholes penetrated the Windsor-Horton contact and were terminated just below this boundary. The Horton Group in this area consists mainly of red and brown sandstone with a few thin shale layers. Lithostratigraphically, these rocks may be correlated with the Cheverie Formation. An assemblage from drillhole SM6 (at 34.45 m), from GSC locality C-146201, lat. 45°15'00"N, long. 63°30'29"W, is representative of these drill cores (Figs. 5.2, 5.5), and resembles the assemblage found in samples of the Coldstream Formation in the Shubenacadie and Musquodoboit basins.

Musquodoboit and Shubenacadie basins (Figs. 5.2, 5.5)

Coldstream Formation

Samples from seven drillhole cores were selected for palynological analysis from the beds lying disconformably beneath the Windsor Group in the Musquodoboit and Shubenacadie basins. Preservation of miospores was so poor in five of the cores that no useful information was obtained. In the other two boreholes (MG-43, GSC locality C-146202, lat. 44°58'27"N, long. 63°11'09"W; and JOMA-4, GSC locality C-146203, lat. 45°04'00"N, long. 63°19'57"W; Figs. 5.2, 5.5), there were continuous sections containing spores between the base of the Windsor Group and the angular unconformity at the top of the Meguma Group. These rocks have been assigned to the Coldstream Formation (Giles and Boehner, 1982), which consists of 50 to 90 m of interbedded conglomerate, sandstone and, more rarely, shale; the abundance of conglomerate differentiates it from the Cheverie Formation. Three samples were collected from MG-43, GSC locality C-146202 (176.6 m, 193.1 m and 240.3 m) and two from JOMA-4, GSC locality C-146203 (75.0 m and 109.73 m).

Cumberland Basin (Figs. 5.2, 5.5)

Diamond Brook Formation

At the eastern end of the Cobequid Highlands, Irving-Chevron drilled the 2638 m deep Irving-Chevron Scotsburn No. 2. well at lat. 45°38'21"N, long. 63°00'10.78"W (GSC

locality C-146226); 30 samples from the cuttings were examined for palynomorphs. The lithotypes, mainly felsic and mafic volcanic rocks are interbedded with minor grey, green or brown shale, siltstone, and in the upper part, sandstone horizons (Fig. 5.5). Donohoe and Wallace (1982) mapped these rocks as part of the Diamond Brook Formation, which conformably overlies the Byers Brook Formation. Rb-Sr isotopic analyses of felsic rocks from the Scotsburn No. 2 well fall on a Rb-Sr whole rock isochron of 341 ± 4 Ma obtained from the Byers Brook Formation (Cormier, 1982, pers. comm.). This may be compared to the 352 ± 8 Ma age indicated for the Tournaisian-Viséan boundary by Palmer (1983). The Diamond Brook is unconformably overlain by the Upper Carboniferous Millsville and superjacent formations (Donohoe and Wallace, 1982); thus, its lithostratigraphic relationship with the Viséan Windsor Group is unknown. Also uncertain is the extent of contamination of samples from caving in the well.

Antigonish Basin (Figs. 5.2, 5.4, 5.5)

Wilkie Brook Formation, type section

The Wilkie Brook Formation was formally defined by Keppie, Giles and Boehner (1978) as the 206 m thick succession of conglomerate, sandstone, shale and limestone that underlies the Marsh Cove Limestone (a lateral equivalent of the Macumber Formation, the basal unit of the Windsor Group) but overlies, with angular unconformity, Upper Devonian rocks. The type section is exposed 380 m north of the mouth of Wilkie Brook, on the western shore of St. Georges Bay (Figs. 5.2, 5.4Ai, 5.5). The lower part of the Wilkie Brook Formation is mainly red polymictic conglomerate and sandstone grading upward into interbedded conglomerate, sandstone, siltstone, shale and limestone; the upper part consists predominantly of conglomerate. The limestone beds are typically thin, discontinuous, locally oolitic and algal, and are probably of lacustrine origin. Nevertheless, as a check for marine provenance, nine samples were processed for conodonts; all were barren. Although the Marsh Cove Limestone is commonly brecciated with folded, finely laminated zones and recrystallized patches, it appears to overlie the Wilkie Brook Formation concordantly. Lithostratigraphic correlation of the Wilkie Brook Formation with the type section of the Horton Group is uncertain. Samples (from GSC localities C-136348, C-136349, C-136350, C-140201, C-140202, C-140203, and C-140250) were collected for palynological analysis from the shale units within the Wilkie Brook Formation (Fig. 5.5).

Unnamed formation, Lakevale Section *(Figs. 5.2, 5.4, 5.5)*

At Lakevale, south of Wilkie Brook, two sequences of clastic rocks occur on the north and south limbs of a syncline, the core of which contains rocks of the Windsor Group. In the northern sequence (Fig. 5.5), the upper part of the section correlates lithostratigraphically with the lower part of the Wilkie Brook Formation. A conglomerate horizon at the base of the Wilkie Brook Formation lies disconformably on about 200 m of interbedded sandstone, conglomerate, siltstone and shale cut by faults of unknown, but presumed small, displacement. Thirteen samples (from GSC localities C-146212 to C-146224) were collected from the unit beneath the Wilkie Brook Formation (Fig. 5.4Aiii); eight were productive. The sample from GSC locality C-146224 is the only sample that included beds with thin coal partings, a feature reminiscent of the lower member of the Horton Bluff Formation.

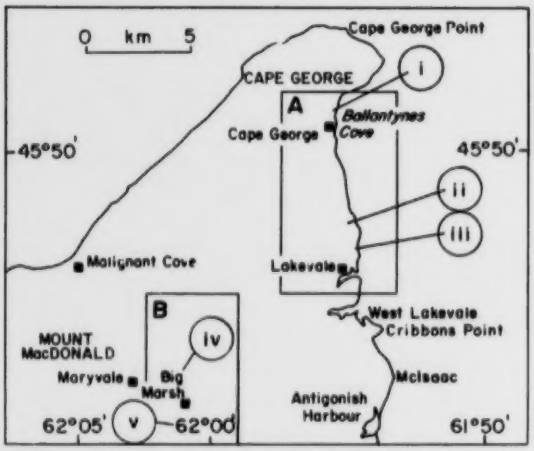


Figure 5.4. *Location of sections in Antigonish Basin. Rectangles A and B are enlarged in Figures 5.4A and 5.4B.*

Localities i to iii, and iv to v are shown in Figures 5.4A and 5.4B, respectively, along with GSC locality numbers, e.g. C-140250.

In contrast, to the south of the syncline, possible correlatives of the Wilkie Brook Formation are reduced to a 1 to 2 m thick conglomerate unit. This thin conglomerate rests with angular unconformity on a sequence of sandstone with thin shale interbeds (GSC locality C-146225); the erosional base has an observable relief of 0.25 m. Toward the top of the unit, fine to medium grained sandstone and siltstone intercalations lie conformably beneath laminated limestone of the Macumber Formation, the basal unit of the Windsor Group (Fig. 5.5). One sample (from GSC locality C-161430) was collected from the topmost siltstone intercalation, but yielded palynomorphs.

Rights River Formation, Big Marsh and Beaver Settlement boreholes *(Figs. 5.2, 5.4, 5.5)*

Nine shallow holes were drilled by the Nova Scotia Department of Mines and Energy (Macauley and Ball, 1984) to investigate the oil shales in the Horton Group (Rights River Formation) north of Antigonish (holes DDH 1, DDH 5-8, and DDH 9 at Big Marsh and DDH 2-4 at Beaver Settlement). The holes at Big Marsh were spudded about 200 m below the base of the Windsor Group. Regional stratigraphic relationships suggest that the holes at Beaver Settlement were spudded in rocks lying beneath an angular unconformity at the base of the Wilkie Brook Formation. Interbedded grey siltstone, shale and sandstone are present in all the cores. Four samples were collected from Big Marsh DDH 1 (Fig. 5.4Biv), GSC locality C-146228, lat. 45°44'45"N, long. 62°00'12"W (16.0 m, 17.86 m, 26.0 m and 46.02 m), and three samples from DDH 9 (Fig. 5.4Bv), GSC locality C-140209, lat. 45°42'50"N, long. 62°01'12"W (31.08-32.61 m, 56.39-57.91 m, and 109.12-110.64 m). Preservation of miospores was poor, but thermal maturity data were obtained. Two samples were collected from the oil shales in Beaver Settlement DDH 2, GSC locality C-146227, lat. 45°48'12"N, long. 61°55'08"W (70.26 m and 73.15 m), and two from DDH 4, GSC locality C-140209, lat. 45°48'10"N, long. 61°55'30"W (39.01-40.54 m and 49.70-51.21 m).

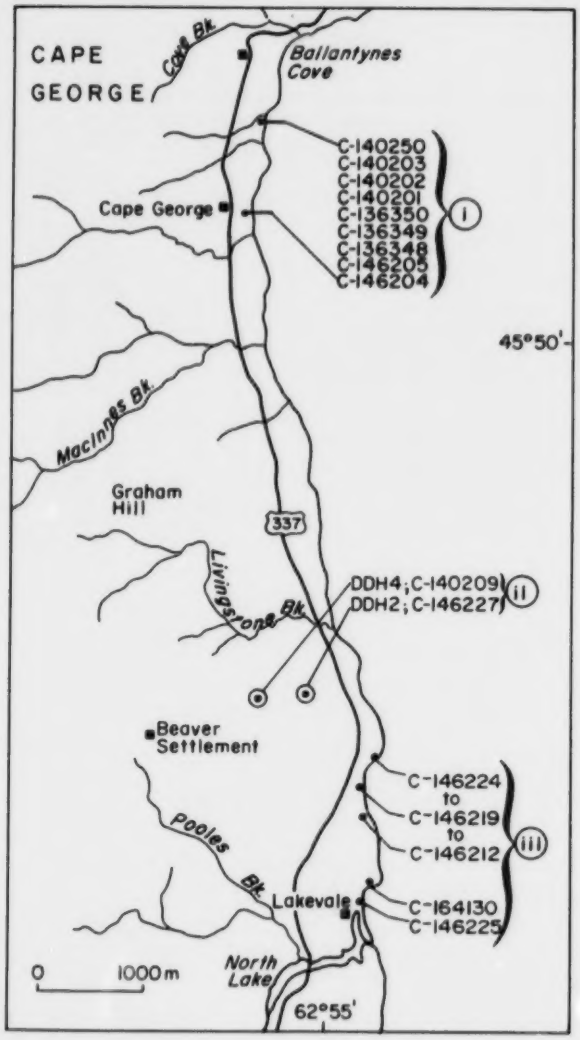


Figure 5.4A.

i = *Wilkie Brook cliff section, Wilkie Brook Formation (type section).*
ii = *Drillholes DDH 2 and DDH 4, oil shales of Rights River Formation.*
iii = *Lakevale cliff section, unnamed formation.*

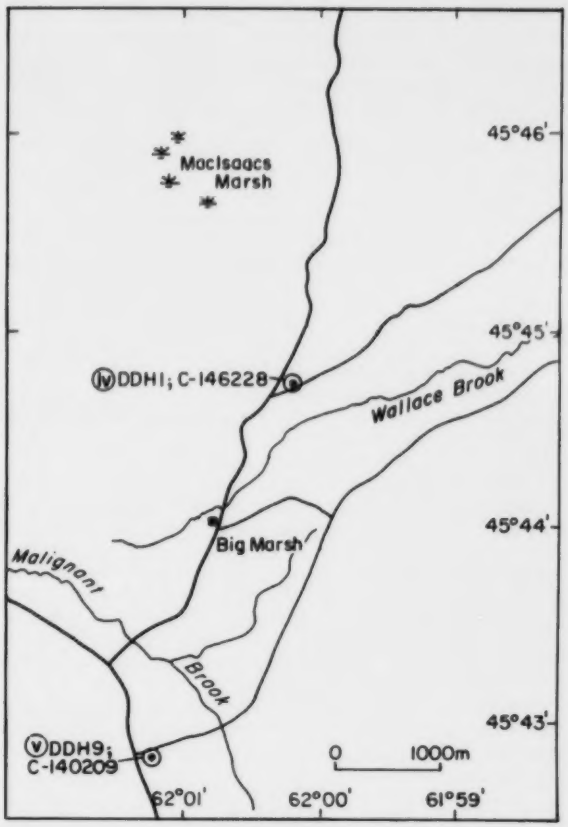


Figure 5.4B.

iv = *Drillhole DDH 1, Rights River Formation.*
v = *Drillhole DDH 9, Rights River Formation.*

STRATIGRAPHIC PALYNOLOGY

The spore assemblages from the sections studied are summarized below, commencing with the type area of the Horton Bluff and Cheverie formations; in addition, a composite list of all species found is given in Table 5.1. Productive samples are indicated in Figure 5.5.

Acritarchs (e.g., *Diexallophasis remota* (Deunff) Playford, 1977, *Michrystridium* spp., *Veryhachium downiei* Stockmans and Willière, 1962, and *V. europaeum* Stockmans and Willière, 1962) occur in some of the samples, but it is not certain if these are reworked from pre-Carboniferous rocks, or whether they are Carboniferous taxa *in situ*. There are very few published data on Carboniferous acritarchs. Some of the specimens found (*Veryhachium downiei* and *V. europaeum*) are of marine origin, yet no marine macrofaunas have been found in the Horton Group, nor were any conodonts found in samples of carbonate rocks from the type areas of the Horton Bluff Formation (GSC locality C-136336, Fig. 5.3Biii) or from the Wilkie Brook Formation type section (Fig. 5.4Ai). This lack of data to support a marine environment would indicate that the acritarchs were reworked.

Horton Bluff Formation type area (Windsor Basin) (Figs. 5.3, 5.5, 5.6)

Lower member

Samples from the lower member of the Horton Bluff Formation obtained from borehole Saarberg Interplan Canada Limited Sl/8 contained assemblages characterized by the presence of *Umbonatisporites abstrusus* (common in GSC locality C-136340 - 95.0 m) and *Umbonatisporites distinctus*, and the abundance in many samples of *Vallatisporites vallatus*. *Vallatisporites verrucosus* is present and may be common to abundant. Species of *Punctatisporites* are common. *Spelaeotriletes cabotii* is common in one sample (GSC locality C-136340 - 70.0 m). *Verrucosisporites nitidus* and *Neoraistrickia logani* occur rarely. *Grandispora uncata* is common in some samples.

Other species include: *Dictyotriletes trivialis*, *Discernisporites micromanifestus*, *Spelaeotriletes echinatus*, *Knoxisporites literatus*, *Leiozonotriletes insignitus*, *Pustulatisporites gibberosus*, *Raistrickia baculosa*, *Raistrickia clavata*, and *Schopfites augustus*.

In the upper part of the lower member, samples collected from Curry Brook yield rare, poorly preserved specimens including *Anapiculatisporites hystricosus*, *Cyclogranisporites commodus*, *Grandispora uncata*, *Pustulatisporites gibberosus*, *Punctatisporites glaber*, *Vallatisporites vallatus* and *Vallatisporites verrucosus*.

Middle member

Material from Curry Brook from the lower part of the middle member contains assemblages similar to those from the lower member that include *Umbonatisporites abstrusus* and *Umbonatisporites distinctus*.

Assemblages from the upper part of the middle member of the Horton Bluff Formation at Horton Bluff (Figs. 5.3Bvi, 5.5, 5.6) were not significantly different from those in the lower member, although *Umbonatisporites abstrusus* and *Umbonatisporites distinctus* are absent, and *Spelaeotriletes cabotii* is common to abundant in many of the samples. In one sample (from GSC locality C-136314) *S. cabotii* is dominant. *Schopfites claviger* and *Diatomozonotriletes rarus* occur rarely. Reworked(?) acritarchs occur in some samples.

A sample (GSC locality C-97746) from the top of the middle member along Hurd Creek (Figs. 5.3Biv, 5.5, 5.6) contained an assemblage similar to those in samples from the type section.

Upper member

Samples collected from the upper member on Hurd Creek (Figs. 5.3Biv, 5.5, 5.7) yielded assemblages similar to those of the upper part of the middle member.

Beds of uncertain stratigraphic position, Lakevale Section (Antigonish Basin) (Figs. 5.2, 5.4Aii, 5.5, 5.7)

Upper beds

Rocks in the upper part of Lakevale section lithologically resemble the lower member of the Horton Bluff Formation, and contain an assemblage dominated by *Spelaeotriletes cabotii* (GSC locality C-146224). This assemblage is qualitatively similar to those from the lower member and lower middle member of the Horton Bluff Formation and contains *Umbonatisporites distinctus*.

Lower beds

Faulted against the upper unit are beds (GSC localities C-146216 to C-146220) containing assemblages that have some features in common with the Horton Bluff and Cheverie material. For example, *Knoxisporites literatus*, *Grandispora uncata*, *Vallatisporites vallatus* and *Vallatisporites verrucosus* are present. *Umbonatisporites distinctus* has been noted, a species seen only in the lower member and the lower part of the middle member of the Horton Bluff Formation. *Verrucosisporites nitidus* is common in one sample (from GSC

TABLE 5.1

Composite list of miospore species found in samples studied, Horton Group (revised)

Anapiculatisporites hystricosus Playford, 1964
Auroraspora macra Sullivan, 1968
Chomotriletes multivittatus Playford, 1978
Colatisporites decorus (Bharadwaj and Venkatachala) Williams, 1978
Convolutispora flexuosa forma *major* Hacquebard, 1957
Convolutispora sp. cf. *C. finis* Love, 1960
Convolutispora vermiformis Hughes and Playford, 1961
Crassispora trychera Neves and Ioannides, 1974
Cristatisporites aculeatus (Hacquebard) Potonié, 1960
Cristatisporites submarginatus (Playford) Utting, 1987a
Cyclogranisporites commodus Playford, 1964
Cymbosporites acutus (Kedo) Byvscheva, 1985
Diatomozonotriletes rarus Playford, 1963
Dictyotriletes trivialis Naumova in Kedo, 1963
Discernisporites macromanifestus (Hacquebard) Utting, 1987a
Discernisporites micromanifestus (Hacquebard) Sabry and Neves, 1971
Emphanisporites rotatus McGregor, 1961
Emphanisporites sp. cf. *E. rotatus* McGregor, 1961
Grandispora uncata (Hacquebard) Gupta, 1969
Granulatisporites crenulatus Playford, 1964
Granulatisporites microgranifer (Ibrahim) Potonié and Kremp, 1955
Hymenozonotriletes explanatus (Luber) Kedo, 1963
Knoxisporites literatus (Waltz) Playford, 1963
Latosporites sp.
Leiotriletes ornatus Ishchenko, 1956
Leiotriletes sp. A Utting
Leiozonotriletes insignitus Hacquebard, 1957
Lophozonotriletes malevkensis Naumova in Kedo, 1963
Microreticulatisporites hortonensis Playford, 1964
Neoraistrickia logani (Winslow) Coleman and Clayton, 1987
Punctatisporites glaber (Naumova) Playford, 1962
Punctatisporites irrasus Hacquebard, 1957
Pustulatisporites gibberosus (Hacquebard) Playford, 1964
Raistrickia baculosa Hacquebard, 1957
Raistrickia clavata Hacquebard, 1957
Raistrickia corynoges Sullivan, 1968
Raistrickia ponderosa Playford, 1964
Retusotriletes avonensis Playford, 1964
Retusotriletes crassus Clayton in Clayton et al., 1980
Retusotriletes incohatus Sullivan, 1964
Retusotriletes triangulatus (Streel) Streel, 1967
Rugospora minuta Neves and Ioannides, 1974
Rugospora polyptycha Neves and Ioannides, 1974
Schopfites augustus Playford, 1964
Schopfites claviger Sullivan, 1968
Schopfites delicatus Higgs, 1975
Spelaeotriletes cabotii sp. nov. Utting
Spelaeotriletes echinatus (Hacquebard) Utting, 1987a
Spelaeotriletes pretiosus (Playford) Neves and Belt var. *bellii* Utting, 1987a
Spelaeotriletes pretiosus (Playford) Neves and Belt var. *pretiosus*
Umbonatisporites abstrusus (Playford) Clayton, 1971
Umbonatisporites distinctus Clayton, 1971
Vallatisporites ciliaris (Luber) Sullivan, 1964
Vallatisporites vallatus Hacquebard, 1957
Vallatisporites verrucosus Hacquebard, 1957
Verrucosisporites congestus Playford, 1964
Verrucosisporites nitidus Playford, 1964
Verrucosisporites papulosus Hacquebard, 1957

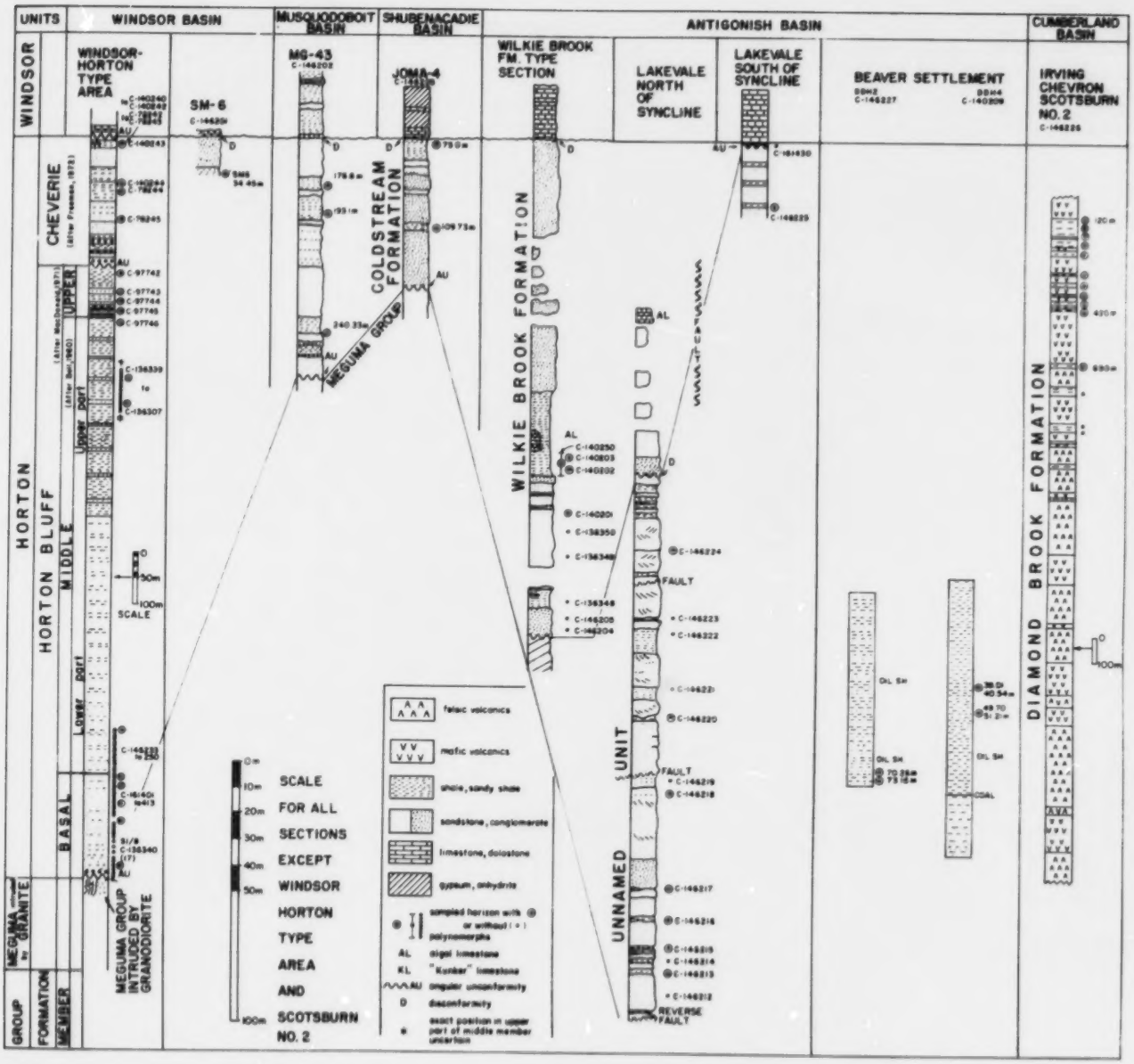


Figure 5.5. *Lithology of sections and position of samples of material collected from the Windsor, Shubenacadie, Musquodobit, Cumberland and Antigonish basins. Productive samples indicated.*

locality C-146225); it is rare in the Horton Bluff material, but may be common in the Cheverie. However, the samples contain taxa not seen in either the Horton or Windsor Group assemblages. Species include *Cymbosporites acutus*, *Emphanisporites rotatus*, *Hymenozonotriletes explanatus*, and *Lophozonotriletes malevkensis*.

An assemblage similar to that outlined for samples from GSC localities C-146216 to C-146220 occurs in the Lakevale section (GSC locality C-146225), south of the syncline in beds overlain unconformably by the Windsor Group.

Probable lateral equivalents of part of the type Horton Bluff Formation (These are probably equivalent in part to the Rights River Formation)

Nova Scotia Department of Mines and Energy, Beaver Settlement drillholes, Antigonish Basin *(Figs. 5.2, 5.4Aii, 5.5, 5.7)*

DDH 2, GSC locality C-146227 (70.26 m and 73.15 m) and DDH 4, GSC locality C-153025 (39.01-40.54 m and 49.70-51.21 m) contain abundant *Spelaeotriletes cabotii* and common *Vallatisporites verrucosus* and *Vallatisporites vallatus*. Rare, reworked lower Paleozoic acritarchs occur in

the lower sample (DDH 2, 73.15 m). In DDH 4, rare specimens of *Umbonatisporites distinctus* occur. *Botryococcus* sp. occurs commonly in DDH 4 (39.01-40.54 m and 49.70-51.21 m). The presence of *U. distinctus* suggests a correlation with assemblages from the lower member to lower middle member of the Horton Bluff Formation.

Irving-Chevron Scotsburn no. 2; GSC locality C-146226 Cumberland Basin (Figs. 5.2, 5.5, 5.7)

Spelaeotriletes cabottii is abundant. In addition *Vallatisporites vallatus* is common in some samples. *Umbonatisporites distinctus* is rare in the sample from 650 m. This assemblage may be correlated with the lower member and lower part of the middle member of the Horton Bluff Formation.

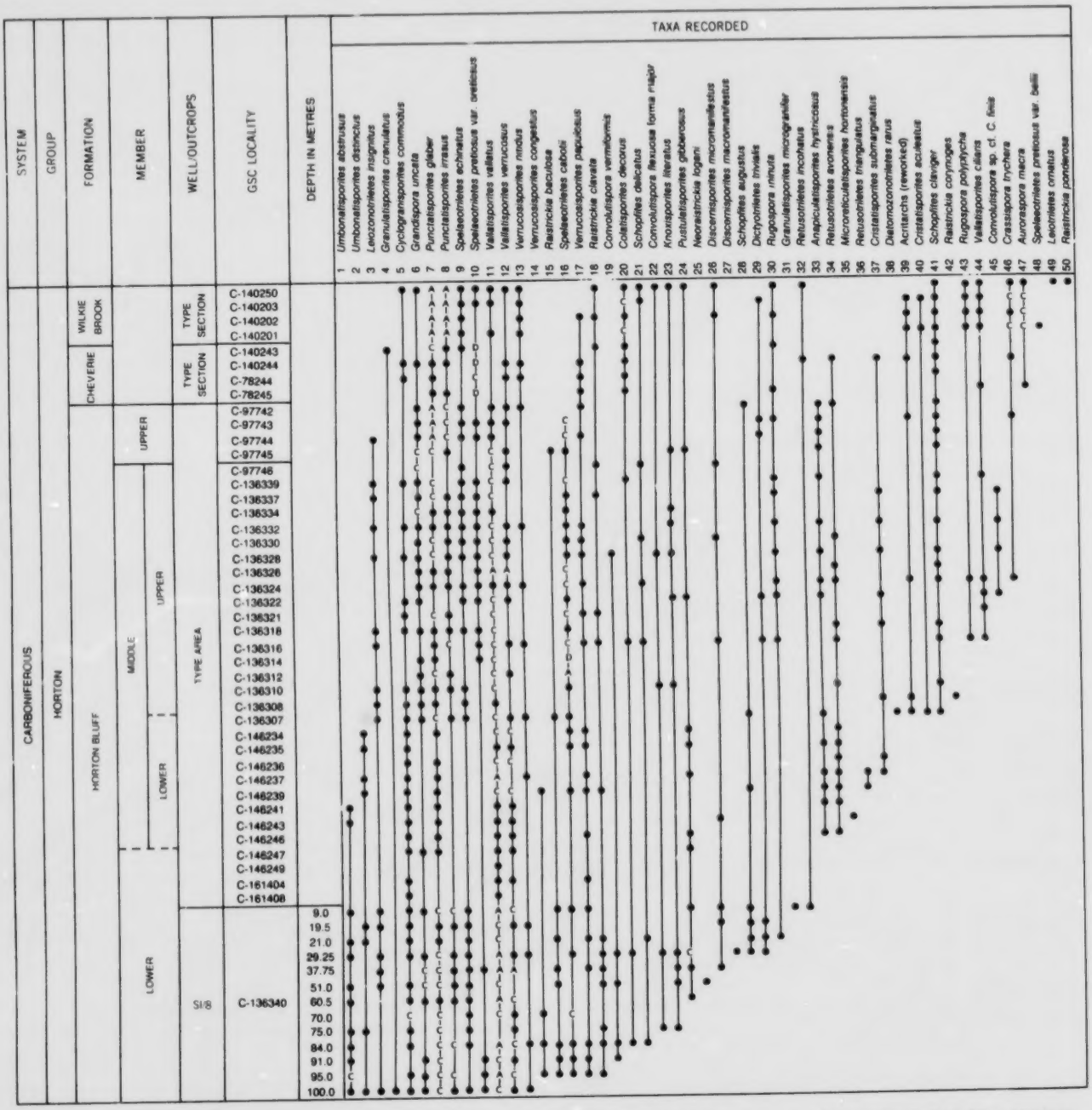


Figure 5.6. *Vertical distribution and relative proportion of palynomorphs present in unnamed formation and in type sections of Horton Bluff, Cheverie and Wilkie Brook formations.*

• = present (1-10); C = common (11-50); A = abundant (>50); D = dominant (>90%); 250 specimens counted.

Cheverie Formation type section (Windsor Basin) (Figs. 5.3Bv, 5.5, 5.6)

A consistent feature of the Cheverie Formation assemblages is a lack of variety and the dominance (approximately 90%) of *Spelaeotriletes pretiosus* var. *pretiosus*. In addition to the species recorded by Playford, rare specimens of *Colatisporites decorus*, *Crassispora trychera*, *Rugospora minuta* and *Schopfites claviger* were seen. Rare, reworked(?) acritarchs occur in some samples. Specimens from a sample (GSC plant locality 6407), originally studied by Playford (1964, p. 4) from the west shore of the Avon River, Nova Scotia, are also used to illustrate some typical Cheverie species.

Wilkie Brook Formation type section (Antigonish Basin) (Figs. 5.2, 5.4Ai, 5.5, 5.6)

Barss (in Keppie et al., 1978) identified spores from a single sample; these data were supplemented by studying three additional productive samples. These contain many species that occur in both the Horton and Windsor groups. These include *Auroraspora macra*, *Colatisporites decorus*, *Crassispora trychera*, *Discernisporites micromanifestus*, *Grandispora uncata*, *Punctatisporites irrasus*, *Punctatisporites planus*, *Rugospora minuta*, *Rugospora polyptycha*, *Schopfites claviger*, *Spelaeotriletes echinatus*, *Spelaeotriletes pretiosus* var. *bellii*, *Spelaeotriletes pretiosus* var. *pretiosus*, *Vallatisporites ciliaris*, *Vallatisporites vallatus*, *Vallatisporites verrucosus*, and *Verrucosisporites nitidus*.

Elsewhere, *Vallatisporites vallatus* and *Vallatisporites verrucosus* are found only in the Horton Group. *Lycospora pusilla*, *Lycospora noctuina* var. *noctuina*, and *Knoxisporites stephanephorus*, important diagnostic species of the Windsor Group, were not seen in any of the Wilkie Brook Formation samples. There is a quantitative dominance of *Punctatisporites glaber* and *P. irrasus*, and *Spelaeotriletes echinatus* and *Colatisporites decorus* are common, whereas assemblages from the Windsor Group are generally dominated by *Crassispora trychera* and *Rugospora minuta* (Utting, 1987a), and those from the upper part of the Horton Group (Cheverie Formation) are dominated by *Spelaeotriletes pretiosus* var. *pretiosus*. Algae(?) occur in some samples. One sample (from GSC locality C-140202) contains reworked (lower Paleozoic) acritarchs. (Rare reworked(?) acritarchs occur in some samples in the Cheverie and Horton Bluff formations and in the Windsor Group). The rocks lying unconformably beneath the Wilkie Brook Formation yielded Upper Devonian spores (Benson 1970, 1974).

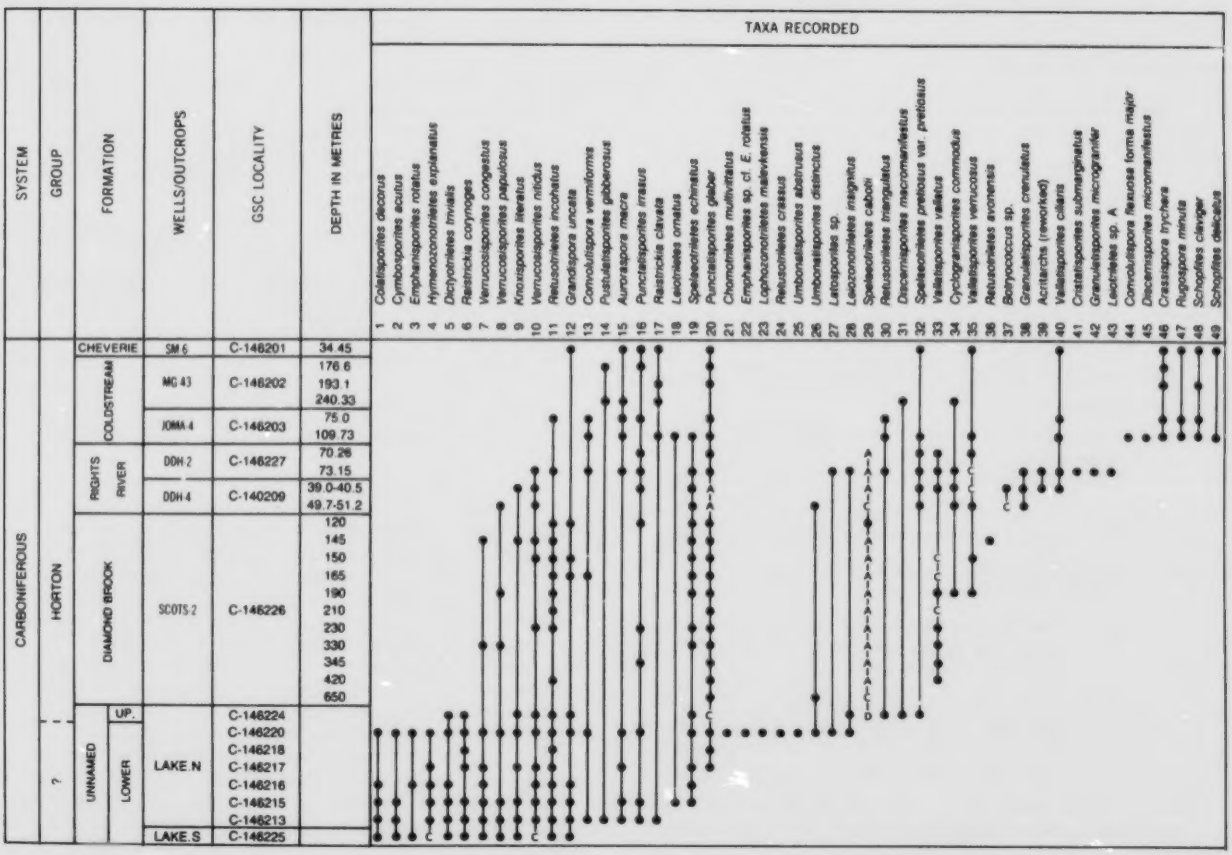


Figure 5.7. *Vertical distribution and relative proportion of palynomorphs in unnamed formation, Diamond Brook, Rights River, Coldstream, and Cheverie formations.*

• = present (1 = 10); C = common (11 = 50); A = abundant (>50); D = dominant (>90%); 250 specimens counted.

Coldstream Formation (Musquodoboit and Shubenacadie basins) (Figs. 5.2, 5.5; 5.7)

Five Mile River and Latties Brook boreholes. Joma 4, GSC locality C-146203 (75.0-109.73 m); Mg 43, GSC locality C-146202 (92.81-240.33 m). Also SM 6, GSC locality C-146201 (34.45 m).

All of the assemblages found in these cores are poorly preserved. Only a few specimens are identifiable, but the assemblages are generally similar to those from the Wilkie Brook Formation. Slight differences are quantitative: *Spelaeotriletes echinatus* and *Colatisporites decorus* are common in the Wilkie Brook Formation, but not in the Coldstream.

Lower Windsor Group, Nova Scotia

The Lower Windsor assemblages are dominated by *Rugospora minuta* and *Crassispora trychera*, and belong to the *Lycospora noctuina* var. *noctuina* – *Knoxisporites stephanephorus* (NS) Zone of Utting, 1987a. Present are *Lycospora pusilla, L. noctuina, Knoxisporites stephanephorus*, and *Vallatisporites ciliaris*. There are no obvious palynological differences between macrofaunal Subzones A and B of the Windsor Group throughout Atlantic Canada. However, at Stewiacke, Shubenacadie Basin, Nova Scotia, the poorly preserved assemblages from the lower part of macrofaunal Subzone A lack *Lycospora* spp. and *Knoxisporites stephanephorus*; in addition *Grandispora uncata* and *Vallatisporites verrucosus* occur in significant numbers (Assemblage Zone I(?) of Utting, 1980). It is not clear if this assemblage should be correlated with the Coldstream and Wilkie Brook material or whether it represents a poor Windsor Group assemblage with reworking from the Horton Group.

SUMMARY OF ASSEMBLAGE ZONES (Fig. 5.8)

Four informal, local assemblage zones and two subzones have been recognized in this study. They are:

i) *Colatisporites decorus* – *Schopfites claviger* Assemblage Zone of the Wilkie Brook and Coldstream formations.

ii) *Spelaeotriletes pretiosus* var. *pretiosus* Assemblage Zone of the Cheverie Formation.

iii) *Vallatisporites vallatus* Assemblage Zone from the Horton Bluff Formation.

  a) *Spelaeotriletes cabotii* Assemblage Subzone from the upper middle member and upper member of the Horton Bluff.

  b) *Umbonatisporites abstrusus* – *Umbonatisporites distinctus* Assemblage Subzone from the lower member and lower part of the middle member of the Horton Bluff.

iv) *Emphanisporites rotatus* – *Hymenozonotriletes explanatus* Assemblage Zone from the unnamed formation (except its uppermost part).

Unfortunately the various sections studied are relatively thin (less than 150 m) and are found at widely dispersed localities. Because the relative lithostratigraphic and biostratigraphic relationships are therefore uncertain, it is not possible to determine the precise level at which species first appear or to establish reliable concurrent range zones as defined in the North American Commission on Stratigraphic Nomenclature (1983). Therefore, the assemblage zone (or cenozone) concept has been used in this work where the zone is characterized by taxa without taking into account their range limits; the zones proposed are informal.

At present it is not clear which of the microfloral changes are of evolutionary significance, and which are environmentally induced. The variation in sedimentary environments (fluviatile and lacustrine) that occurred during deposition of the Horton Group would almost certainly have influenced the composition of the spore assemblages.

There are two possible interpretations of the data. They are that 1) all of the assemblage zones and subzones are of different ages, and 2) some of the assemblage zones and subzones may be of different ages; others may be of similar ages, but may differ slightly from one another qualitatively and quantitatively because they were deposited in different sedimentary facies.

Minor qualitative and quantitative variations within the Tournaisian spore assemblages may occur over a wide geographic area in Atlantic Canada, and these may be useful for obtaining finer biostratigraphic zonation than is currently possible by using correlation with the spore zones of Western Europe. Further detailed work needs to be carried out, especially in New Brunswick and western Newfoundland, to verify this.

For example, *Umbonatisporites abstrusus* and *U. distinctus* appear to be biostratigraphically useful for subdividing the Tournaisian, although *U. distinctus* is known to occur in Viséan rocks of Western Europe and Australia (Clayton, 1985). Also, the dominance of *Spelaeotriletes pretiosus* var. *pretiosus* in the Cheverie Formation may prove to be useful locally, although this assemblage may be an abundance zone reflecting strong local ecological control.

In spite of these uncertainties, a preliminary zonation scheme based on the currently available data has been determined, and is presented in Figures 5.8 and 5.9.

ASSEMBLAGE ZONES AND CORRELATION

Precise biostratigraphic correlation of the Horton Group with lateral equivalents in other parts of Atlantic Canada is not yet possible because of insufficient data, except possibly the oil-shale-bearing Albert Formation of New Brunswick (Utting, 1987b). Albert assemblages have many features in common with those from the lower member and the lower middle member of the Horton Bluff Formation: for example, the presence of *Umbonatisporites distinctus, U. abstrusus, Vallatisporites vallatus, V. verrucosus, Spelaeotriletes cabotii*, and *S. pretiosus*. There are also similarities between these Horton and Albert assemblages, and those from the oil shale of the Rights River Formation of the Antigonish Basin (drillhole DDH 4). This suggests that oil shale deposition probably occurred at about the same time in southeastern New Brunswick and in the Antigonish Basin. Also similar to those of the lower and lower middle member of the Horton Bluff Formation are assemblages from part of the Diamond Brook Formation of the Cumberland Basin; in the lowest sample studied (from GSC locality C-146226 – 650 m) *Umbonatisporites distinctus* occurs and *Spelaeotriletes cabotii* is common.

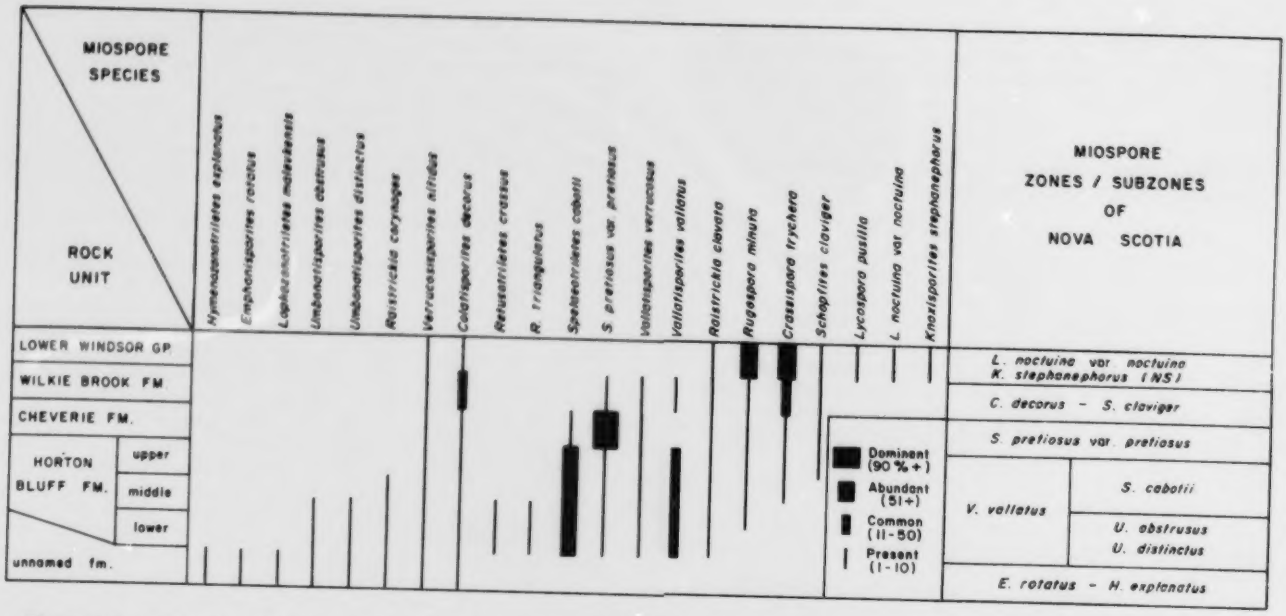


Figure 5.8. *Vertical qualitative and quantitative distribution of stratigraphically important taxa from units in study area, and probable palynostratigraphic correlation with the spore zones of Western Europe.*

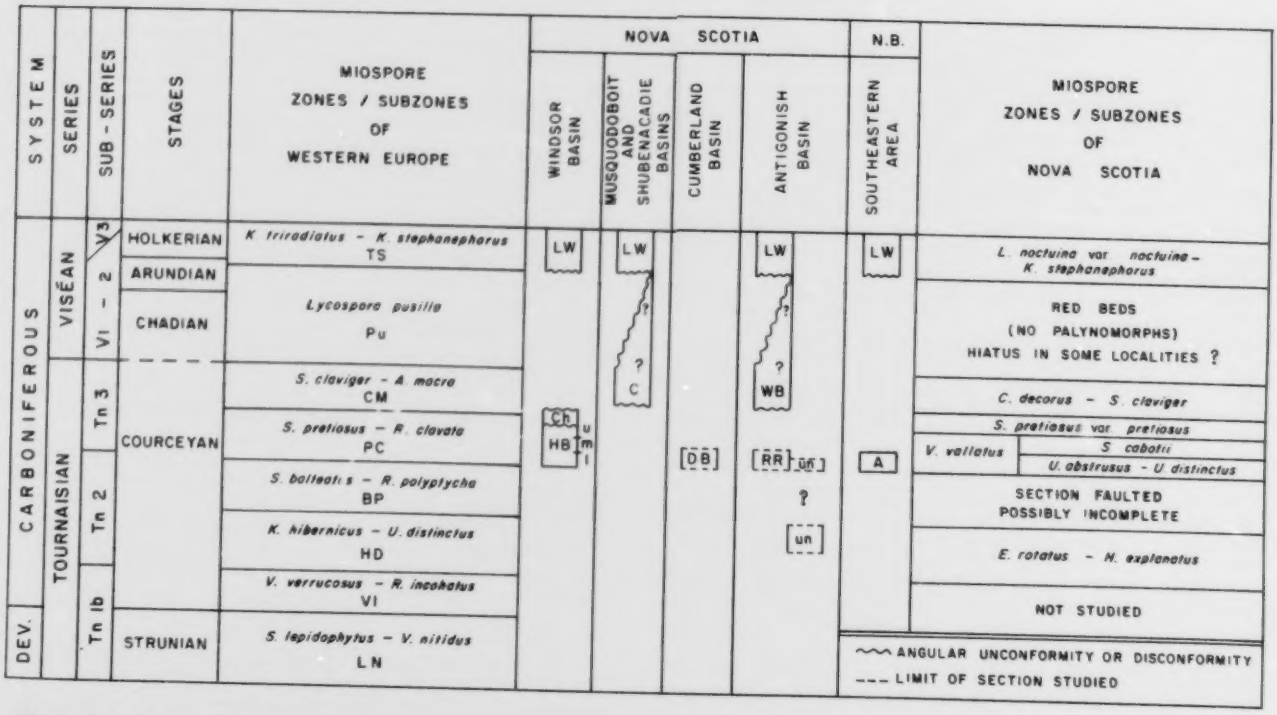


Figure 5.9. *Comparison of age determinations for formations studied from the Windsor, Musquodoboit, Shubenacadie, Cumberland, and Antigonish basins of Nova Scotia, and for those of southeastern New Brunswick. Palynostratigraphic correlation made with the spore zones of Western Europe, as defined by Clayton et al., 1977 and 1978, and Clayton, 1985; probable ages in terms of British and Belgian stages are given.*

LW = Lower Windsor Group; C = Coldstream Formation; WB = Wilkie Brook Formation; Ch = Cheverie Formation; HB = Horton Bluff Formation; DB = Diamond Brook Formation; RR = Rights River Formation; un = unnamed formation.

In the following section, the zones are discussed and correlations are made with the zonal scheme of Western Europe (Fig. 5.9) proposed by Clayton (1985) and Higgs et al. (1988).

The *Emphanisporites rotatus – Hymenozonotriletes explanatus* Assemblage Zone (Figs. 5.8, 5.9)

Palynostratigraphically characteristic species include *Emphanisporites rotatus*, *Retusotriletes incohatus*, *R. triangulatus*, *R. crassus*, *Cymbosporites acutus*, *Verrucosisporites nitidus*, *Raistrickia corynoges*, *Hymenozonotriletes explanatus*, *Knoxisporites literatus*, *Lophozonotriletes malevkensis*, *Latosporites* sp., *Umbonatisporites abstrusus*, and *U. distinctus*. This assemblage is typical of the *Kraeuselisporites hibernicus – Umbonatisporites distinctus* (HD) Zone of Western Europe, where *Umbonatisporites distinctus* first appears, and which is of early Tn_2 age (Clayton, 1985).

***Vallatisporites vallatus* Assemblage Zone**

a. The *Umbonatisporites abstrusus – Umbonatisporites distinctus* Assemblage Subzone (Figs. 5.8, 5.9)

Some species similar to those found in the underlying subzone persist but *Hymenozonotriletes explanatus*, *Emphanisporites rotatus*, *Retusotriletes crassus*, and *Lophozonotriletes malevkensis* are absent.

Species include *Punctatisporites irrasus*, *Retusotriletes incohatus*, *R. triangulatus*, *Verrucosisporites nitidus*, *Dictyotriletes trivialis*, *Vallatisporites vallatus*, *V. verrucosus*, *Auroraspora macra*, *Rugospora polyptycha*, *Spelaeotriletes echinatus*, *Umbonatisporites abstrusus*, *Umbonatisporites distinctus*, *Raistrickia clavata*, and *Spelaeotriletes cabotii*.

The presence of *Umbonatisporites abstrusus* and/or *Umbonatisporites distinctus* is possibly of value in the regional correlation of Atlantic Canada, although in Western Europe *U. distinctus* occurs in rocks from the HD Zone through to the *Lycospora pusilla* (Pu) Zone of Viséan age (Clayton et al., 1978 and Clayton, 1985). However, in Western Canada, *U. distinctus* is known to occur in association with *Retispora lepidophyta* in late Devonian rocks of the Banff Formation (McGregor, pers. comm., 1987), and in the Bakken Formation of late Devonian age in Saskatchewan (Utting, personal observation). The presence of rare specimens of *S. pretiosus* var. *pretiosus* in some samples, and the occurrence of *Vallatisporites vallatus*, and *Raistrickia clavata* throughout the zone indicates an age no older than the *Spelaeotriletes pretiosus – Raistrickia clavata* PC Zone of Western Europe.

Clayton (1985) suggested that the base of the PC zone correlates with a level within late Tn_2. The age of the upper part of the zone is not certain, but probably lies within Tn_{3a} to lowermost Tn_{3c} of Belgium (Clayton et al., 1978). In Ireland, the *Spelaeotriletes balteatus – Rugospora polyptycha* (BP) Zone overlies the HD Zone and underlies the PC Zone (Higgs et al., 1988).

b. *Spelaeotriletes cabotii* Assemblage Subzone (Figs. 5.8, 5.9)

Most species similar to those found in the underlying subzone persist, but *Umbonatisporites abstrusus* and *U. distinctus* are absent.

Vallatisporites vallatus and *Spelaeotriletes cabotii* are common to abundant. Rare specimens of *Schopfites claviger* and *Crassispora trychera* occur in some samples, and their presence may indicate a position close to the *Spelaeotriletes pretiosus – Raistrickia clavata* PC/*Schopfites claviger – Auroraspora macra* (CM) zonal boundary of Tournaisian (mid Tn_3) age. Clayton et al. (1977) documented the first occurrence of *Crassispora trychera* near the top of the PC Zone.

***Spelaeotriletes pretiosus* var. *pretiosus* Assemblage Zone** (Figs. 5.8, 5.9)

Qualitatively this assemblage has many features in common with the underlying zone, although *Vallatisporites vallatus* was not seen. Quantitatively the assemblage differs from the *Vallatisporites vallatus – Spelaeotriletes cabotii* assemblage by the dominance (90%) of *S. pretiosus* var. *pretiosus*. Further work in Atlantic Canada may show whether this is an abundance biozone of regional or local significance.

It would appear that, like the underlying zone, this assemblage zone occupies a position close to the PC/CM zonal boundary.

The *Crassispora trychera – Colatisporites decorus* Assemblage Zone (Figs. 5.8, 5.9)

Qualitatively the assemblage has many features in common with the underlying zone, but may be distinguished quantitatively by the fact that *Crassispora trychera*, *Auroraspora macra* and *Colatisporites decorus* are common, and *Spelaeotriletes pretiosus* var. *pretiosus* is rare.

Colatisporites decorus, *Auroraspora macra*, *Punctatisporites glaber* and *P. irrasus* are common to abundant; also present are *Verrucosisporites nitidus*, *Schopfites claviger*, and *Crassispora trychera*.

This assemblage could be correlated with the CM Zone, which Clayton et al. (1978) suggested was of late Tn_3 age. The lack of *Lycospora* spp. indicates that the assemblage is older than the *Lycospora pusilla* (Pu) Zone. Barss (in Keppie et al. 1978) recorded *Lycospora torulosa* Hacquebard, but Somers (1972) suggested that this species be excluded from *Lycospora*. Also absent is *Knoxisporites stephanephorus*, which appears in the upper part of the Pu Zone (Neves et al., 1972), and which occurs in the Lower Windsor Group *Lycospora noctuina – Knoxisporites stephanephorus* (NS) Assemblage Zone (Utting, 1987).

A further difference is that the NS Zone is dominated by *Crassispora trychera* and *Rugospora minuta*. *Lycospora noctuina* var. *noctuina*, *Lycospora pusilla* and *Knoxisporites stephanephorus* appear. Present are *Spelaeotriletes pretiosus* var. *bellii* and *S. pretiosus* var. *windsorensis*, but *S. pretiosus* var. *pretiosus* is absent.

A correlation of the NS Zone with the upper part of the Pu Zone, Viséan (V_2 to early V_3) age, was proposed by Utting (1980, 1987a). However, according to the revised zonal scheme of Clayton (1985), and Higgs et al., (1988) a new zone, the *Knoxisporites triradiatus – K. stephanephorus* (TS) Zone has been proposed for this upper part of the previous Pu Zone. Although the NS Zone of Atlantic Canada may be correlated with this new TS Zone (both contain *K. stephanephorus*), *K. triradiatus* appears in Atlantic Canada in the overlying *Schopfipollenites acadiensis – K. triradiatus* (AT) Zone (Utting, 1987a).

ORGANIC MATTER AND THERMAL ALTERATION

Most samples contain various proportions of exinous, woody and coaly fragments. The proportion of amorphous material is generally low, except in some oil shales from the Rights River Formation, where it constitutes approximately 50 per cent of the total and consists mainly of algal material. *Botryococcus* sp. is present there and also occurs in some samples from the lower member of the Horton Bluff Formation in borehole SI/8.

The Thermal Alteration Index, estimated according to the five-point scale of Hunt (1979), and Utting (1987a), varies throughout the study area (Fig. 5.2). The lowest values were obtained in the oil shales of the Rights River Formation at Beaver Settlement (TAI 2- in drillholes DDH 2 and DDH 4), although at Big Marsh in DDH 1 and DDH 9 the thermal alteration is significantly higher than elsewhere in the formation (TAI 3 to 3+). This observation is supported by the work of Macauley and Ball (1984) using Rock-Eval data, and Kalkreuth and Macauley (1986 and 1987) using vitrinite reflectance; vitrinite reflectance values of 0.44 to 0.59 per cent R random were found in DDH 4, whereas 0.62 to 1.31 per cent R random occurred in DDH 9. Low thermal maturity (TAI 2- to 2) also occurs at the type section of the Wilkie Brook Formation, although one sample (from GSC locality C-140202) contains a curious gradation of spore colour from orange to yellow brown (TAI 2) to black (TAI 4). The reason for this is not clear. A similar phenomenon was observed in some samples from salt units of the Windsor Group (Utting, 1987a) where possible causes were movement of salt along narrow planes, or geochemical exchanges between the exinite and salt matrix. Neither of these mechanisms seems applicable here, although some other kind of geochemical activity may have been responsible. There is also no evidence of any reworking. A low TAI value is found in the Horton Bluff Formation in the southwestern part of the Windsor Basin (TAI 2+), but in the remaining localities studied, the TAI varies from 3- to 3. The low TAI value is confirmed by vitrinite reflectance values of 0.71 to 0.80 per cent R_{max} (W.D. Kalkreuth, pers. comm., 1987). The differences in thermal maturity throughout the area have yet to be satisfactorily explained. Variations in depth of burial may have been a factor, but may not have been responsible for the sudden changes that are observed, for example, between Beaver Settlement and Big Marsh, and in the Windsor Basin. Other factors could have been: heating adjacent to Carboniferous plutons, faulting, and tectonic loading.

The thermal maturity data so far available indicate that there was some potential for the generation of liquid hydrocarbons in the Antigonish Basin and in the southwestern part of the Windsor Basin. However, the thermal alteration may have been too high for oil preservation in some localities; these localities may be gas prone.

CONCLUSIONS

Four assemblage zones and two subzones may be recognized:

1. *Emphanisporites rotatus – H explanatus* Assemblage Zone in the lower unnamed formation.

2. *Vallatisporites vallatus* Assemblage Zone in the upper part of the unnamed formation and the Horton Bluff Formation, which is divided into:

   a. *U. abstrusus – U. distinctus* Assemblage Subzone in the upper part of the unnamed formation, and the lower member and lower middle member of the Horton Bluff Formation.

   b. *S. cabotii* Assemblage Subzone in the upper part of the middle member and the upper member of the Horton Bluff Formation.

3. *S. pretiosus* var. *pretiosus* Zone in the Cheverie Formation.

4. *C. decorus – S. claviger* Assemblage Zone in the Wilkie Brook Formation. Assemblages similar to *U. abstrusus – U. distinctus* Assemblage Subzone occur in the oil shales of the Rights River Formation and in part of the Diamond Brook Formation, and assemblages similar to the *C. decorus – S. claviger* Assemblage Zone occur in the Coldstream Formation.

In the Windsor Basin (Fig. 5.2), clastic rocks in the drill core (SM-6) along the northern side of the basin are lithostratigraphically indistinguishable from rocks of the Cheverie Formation in the type section, and we recommend that they be included in that formation. Palynologically, however, they appear to be younger, and are similar to the Coldstream and Wilkie Brook assemblages, although preservation is poor. Such young clastic rocks were probably deposited at the type area, but removed by erosion, as documented by the angular unconformity.

The Coldstream Formation in the Musquodoboit and Shubenacadie basins, and the Wilkie Brook Formation in the Antigonish Basin, are lithologically distinct from the type Cheverie Formation, and palynological analysis indicates they may be slightly younger. However, we recommend that the definition of the Horton Group be expanded to incorporate the Coldstream and Wilkie Brook formations because sedimentologically they have more in common with the fluviatile and lacustrine Horton Group than with the marine Windsor Group. Assemblages from the lowermost Windsor beds of Stewiacke borehole SB-1 remain problematical, although work elsewhere in Atlantic Canada (Utting, 1987a) suggests that the 'Horton' species (*Vallatisporites verrucosus* and *Reticulatisporites cheveriensis*) in the lower part of Subzone A of the Windsor Group may be reworked.

Correlation with Western Europe suggests that:

1. The *Emphanisporites rotatus – Hymenozonotriletes explanatus* Assemblage Zone correlates with the HD Zone of Tn_2 age.

2. The *Vallatisporites vallatus* Assemblage Zone may be correlated with the PC Zone of late Tn_2 to early Tn_3 age.

   a. The *Umbonatisporites abstrusus – Umbonatisporites distinctus* Assemblage Subzone may be assigned to the PC Zone of Tournaisian (late Tn_2 to early Tn_3) age.

   b. The *Spelaeotriletes cabotii* Assemblage Subzone correlates with the upper PC Zone of Tournaisian (early Tn_3) age.

3. The *Spelaeotriletes pretiosus* var. *pretiosus* Zone may be assigned to the PC/CM Zonal boundary and is of Tournaisian (mid Tn_3) age.

4. The *Colatisporites decorus – Schopfites claviger* Zone correlates with the CM Zone (late Tn_3 age). The Lower Windsor Group NS Zone correlates with the TS Zone

(Clayton, 1985) of middle Viséan (V_2) to early late Viséan (V_3) age suggesting that the minimum hiatus so far recognized between the newly defined Horton Group and the Windsor Group is represented in time by part of the Viséan (V_1 and possibly part of V_2). In certain localities, yet to be investigated palynologically, the hiatus may be less or even nonexistent. However, north of Cheverie Point the hiatus is probably more significant, including Tournaisian (late Tn_3) to Viséan (V_1).

In terms of the British stages proposed by George et al. (1976), it would seem reasonable to correlate the unnamed formation and the Horton Group (Horton Bluff, Cheverie, Wilkie Brook and Coldstream formations) with the Courceyan Stage (Fig. 5.9). Thus, if the Lower Windsor Group can be correlated with the late Arundian or Holkerian stages, as indicated in Figure 5.9, then probably only the Chadian and early to middle Arundian is absent in the palynological record. This time interval may be represented by clastic, unfossiliferous rocks in the Wilkie Brook and Coldstream formations.

There is a significant variation in thermal maturity in parts of the Antigonish and Windsor basins, indicating a potential for liquid hydrocarbon and gas generation.

SYSTEMATIC DESCRIPTIONS

The suprageneric classification used is based on that of various authors, especially Waltz (1935), Potonié and Kremp (1954), and Neves and Owens (1966).

Anteturma SPORITES H. Potonié, 1893

Turma TRILETES Reinsch 1881, emend. Potonié and Kremp, 1954

Suprasubturma ACAMERATITRILETES Neves and Owens, 1966

Subturma AZONOTRILETES Luber, 1938

Infraturma LAEVIGATI (Bennie and Kidston), 1956

Genus *Leiotriletes* (Naumova) Potonié and Kremp, 1954

Type species. *L. sphaerotriangulus* (Loose) Potonié and Kremp, 1954.

Leiotriletes sp. A Utting

Plate 5.2, figure 10

Figured specimen. GSC 89932, slide 2, 38.8 x 95.0, GSC loc. C-146227 (73.15 m), Pl. 5.2, fig. 10.

Occurrence. Oil shales of Rights River Formation, Antigonish Basin, Nova Scotia, lat. 45°48'12"N, long. 61°55'08"W.

Description. Trilete spores. Amb rounded triangular, sides convex. Laesurae simple, extend approximately one third of radius. Darkening of exine in contact area. Exine laevigate, approximately 1.5 µm thick.

Diameter. 50 to 56 µm (2 specimens).

Remarks. *Calamospora atava* (Naumova) McGregor 1973 differs in that it has a subcircular amb, but it is similar in having a darkened apical area.

Infraturma MURORNATI Potonié and Kremp, 1954

Genus *Emphanisporites* McGregor, 1961

Type species. *Emphanisporites rotatus* McGregor, 1961.

Emphanisporites rotatus McGregor emend. McGregor 1973

Plate 5.1, figures 16-17; Plate 5.2, figure 1

Figured specimens. GSC 89920, slide 8, 35.7 x 109.6, GSC locality C-146220, Pl. 5.1, fig. 16; GSC 89921, slide 8, 36.3 x 107.0, GSC locality C-146220, Pl. 5.1, fig. 17; GSC 89923, slide 2, 29.3 x 107.0, GSC loc. C-146220, Pl. 5.2, fig. 1.

Occurrence. Lower part of unnamed formation, Lakevale section, lat. 45°47'50"N, long. 61°54'50"W.

Description. Trilete miospores, equatorial outline subtriangular. Laesurae simple, with low, narrow (0.5-1 µm) labra, extending almost to equator. Distal surface laevigate. Proximal surface with up to 15 faint spoke-like ridges in each interradial section. Ridges up to 0.25 µm high, but generally less, widest toward equator, narrowing toward pole, where they fuse to form a darker zone around the proximal pole.

Diameter. 42-61 µm (9 specimens).

Remarks. One unusually large (135 µm), but poorly preserved, specimen of *Emphanisporites* sp. cf. *E. rotatus* (Pl. 5.1, fig. 21) was also seen. It has few (5?) prominent ribs in each interradial sector and is much bigger than the typical specimens (max. 84 µm) described by McGregor (1973). Most specimens, however, are less than 62 µm and are difficult to distinguish from those of *E. rotatus* described by McGregor (1973) from Lower Devonian (Emsian) and Middle Devonian (Eifelian) rocks of Eastern Gaspé, Quebec. The faintness of the ribs of the specimen described here is not a sufficiently reliable criterion for a new species to be proposed; it is also a feature of some Gaspé specimens (McGregor, pers. comm., 1987). Faint ribs occur also on *Emphanisporites obscurus* McGregor 1976, although this species is generally larger than *E. rotatus*.

The possibility that the specimens described here are reworked is considered unlikely for the following reasons: no other species common to the Emsian and Eifelian of Atlantic Canada occur in the samples; *E. rotatus* is known to occur in the uppermost Devonian (Fa2d) and Lower Carboniferous (Tn_3) of Southern Ireland (Clayton et al., 1977); the genus *Emphanisporites* is now known to occur at least in uppermost Devonian rocks of western Europe, north Africa, the U.S.S.R., China, Australia, and eastern N. America (McGregor, pers. comm., 1987).

Suprasubturma CAMERATITRILETES Neves and Owens, 1966

Subturma SOLUTITRILETES Neves and Owens, 1966

Infraturma DECORATI Neves and Owens, 1966

Genus *Spelaeotriletes* Neves and Owens, 1966

Type species. *Spelaeotriletes triangulus* Neves and Owens, 1966.

Spelaeotriletes cabotii sp. nov. Utting

Plate 5.3, figures 8-13 and 15

Holotype. GSC 89954, slide 7, 12.7 x 94.3, GSC loc. C-146224, Pl. 5.3, fig. 8.

Figured specimens. GSC 89955, slide 7, 19.1 x 109.4, GSC loc. C-146224, Pl. 5.3, fig. 9; GSC 89956, slide 7, 37.0 x 93.7, GSC loc. C-146224, Pl. 5.3, fig. 10; GSC 89957, slide 7, 36.6 x 97.0, GSC loc. C-146224, Pl. 5.3, fig. 11; GSC 89958, slide 7, 13.2 x 102.0, Pl. 5.3, fig. 12; GSC 89959, slide 7, 11.1 x 107.8, GSC loc. C-146224, Pl. 5.3, fig. 13; GSC 89960, slide 7, 27.1 x 93.8, GSC loc. C-146224, Pl. 5.3, fig. 15.

Occurrence. Common to abundant in upper unnamed formation, Lakevale section (lat. 45°47'55"N, long. 61°54'45"W) and oil shales of Rights River Formation, Antigonish Basin (lat. 45°48'12"N, long. 61°55'08"W and lat. 45°48'10"N, long. 61°55'30"W); present (in places common to abundant) in lower, middle and upper members, Horton Bluff Formation, Windsor Basin, Nova Scotia. Common to abundant in the Albert Formation, New Brunswick.

Diagnosis. Trilete, camerate, amb subtriangular with rounded apices and convex to almost straight sides. Outline of intexine poorly defined, almost parallel to amb, intexine very thin. Diameter of inner body approximately 50 to 80 per cent of overall diameter. Trilete rays virtually straight, extending almost to margin of intexine; associated folds up to 2 µm in height reach equator, sinuous in outline. Curvaturae imperfectae rarely visible. Exoexine infragranulate, approximately 2 µm thick. Ornament on distal surface consisting mainly of closely spaced verrucae, with subordinate coni, spinae and rarely bacula. Verrucae relatively low (1-2 µm), broadly rounded, bases subcircular (basal width 1.5-5 µm); most verrucae bear a single minute conus or spina approximately 1 µm high, with basal diameter 0.25 to 1 µm.

Toward the pole, verrucae coalesce to form a rugulate pattern in some specimens. Coni, spinae and rare bacula more abundant at equatorial margin than in centre.

Diameter. Overall 49-93 µm, mean 69 µm; inner sac 36-65 µm, 46 µm (35 specimens).

Remarks. Spelaeotriletes cabotii may be distinguished from typical *Spelaeotriletes pretiosus* var. *pretiosus* Utting, 1987a by its denser ornament and smaller diameter; the range in diameter of the latter is 98-195 µm with a mean of 149 µm (Playford, 1963), whereas the mean of *S. cabotii* is 69 µm. Some small specimens of *S. pretiosus* var. *pretiosus* have small, fairly closely spaced ornamentation and are similar to *S. cabotii*, but differ in that the ornamentation does not coalesce toward the distal pole. *Spelaeotriletes balteatus* (Playford) Higgs 1975 differs in possessing an ornament of small simple spinae, although like *S. cabotii* these may coalesce toward the pole to form a rugulate pattern. Specimens of *S. balteatus* illustrated by Higgs et al. (1988, Pl. 13, figs. 1-3) could possibly be assigned to *S. cabotii*. *Spelaeotriletes obtusus* Higgs 1975, differs from *S. cabotii* in that it has an ornament of flat topped bacula, coni and pila.

In the Albert Formation of New Brunswick, the presence of specimens with more closely spaced ornamentation was noted (Utting, 1987b). No new species was proposed because there appeared to be continuous variation between specimens with closely spaced ornamentation and those with sparse ornamentation common in specimens of *Spelaeotriletes pretiosus* var. *pretiosus* from the Cheverie Formation. Further study of numerous specimens in samples from the type area suggests that the dense ornamentation almost invariably occurs in specimens smaller than the large, sparsely ornamented specimens. These smaller specimens are abundant in beds older than the Cheverie Formation, and their formal recognition is of value in refining the biostratigraphic zonation of Tournaisian rocks of Atlantic Canada.

Derivation of name. Named for the explorer John Cabot, who, in 1497, made the first recorded landing in North America since the Vikings.

ACKNOWLEDGMENTS

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PLATES 5.1-5.4

All figures are from negatives and prints that were not retouched.

In the explanation of figures, the species name is followed by the GSC locality number, the slide number, stage co-ordinates and GSC type number. All specimens are in the collections of the Geological Survey of Canada, 601 Booth Street Ottawa, Ontario, Canada.

Stage co-ordinates given in the explanation of plates and in the systematic palynology section are those of Leitz Orthoplan microscope no. 9856599 of the Institute of Sedimentary and Petroleum Geology, Calgary, Alberta, Canada.

The magnification of all illustrated specimens is x500 unless otherwise stated.

PLATE 5.1

Figure 1. *Convolutispora flexuosa* forma *major* Hacquebard, 1957

GSC 89907, slide 2, 39.5 x 107.7, GSC loc. C-140250.

Figure 2. *Anapiculatisporites hystricosus* Playford, 1964

GSC 89902, slide 3, 26.3 x 108.8, GSC loc. C-97742.

Figure 3. *Auroraspora macra* Sullivan, 1968

GSC 89903, slide 7, 31.2 x 95.5, GSC loc. C-146220.

Figure 4. *Chomotriletes multivittatus* Playford, 1978

GSC 89904, slide 2, 46.1 x 101.0, GSC loc. C-146220.

Figures 5, 7. *Colatisporites decorus* (Bharadwaj and Venkatachala) Williams, 1978

5. GSC 89905, slide 10, 22.5 x 105.7, GSC loc. C-140250.

7. GSC 89906, slide 10, 4.6 x 105.8, GSC loc. C-140250.

Figure 6. *Convolutispora vermiformis* Hughes and Playford, 1961

GSC 89909, slide 4, 14.2 x 99.3, GSC loc. C-136340 (108.0 m).

Figure 8. *Convolutispora* sp. cf. *C. finis* Love, 1960

GSC 89908, slide 3, 26.1 x 107.2, GSC loc. C-136340 (75.0 m).

Figures 9, 10. *Crassispora trychera* Neves and Ioannides, 1974

9. GSC 89910, slide 10, 12.8 x 95.0, GSC loc. C-140250.

10. GSC 89911, slide 3, 42.0 x 100.8, GSC loc. C-140250.

Figure 11. *Cristatisporites submarginatus* (Playford) Utting, 1987a

GSC 89913, slide 3, 22.0 x 96.4, GSC loc. C-136307.

Figure 12. *Diatomozonotriletes rarus* Playford 1963

GSC 89916, slide 3, 21.8 x 110.5, GSC loc. C-136307.

Figure 13. *Cristatisporites aculeatus* (Hacquebard) Potonié, 1960

GSC 89912, slide 3, 37.4 x 106.9, GSC loc. C-140203.

Figure 14. *Cyclogranisporites commodus* Playford, 1964

GSC 89914, slide 10, 21.4 x 108.6, GSC loc. C-140250.

Figure 15. *Discernisporites micromanifestus* (Hacquebard) Sabry and Neves, 1971

GSC 89919, slide 10, 35.4 x 100.5, GSC loc. C-140250.

Figures 16, 17. *Emphanisporites rotatus* McGregor, 1961

16. GSC 89920, slide 8, 35.7 x 109.6, GSC loc. C-146220.

17. GSC 89921, slide 8, 36.3 x 107.0, GSC loc. C-146220.

Figure 18. *Discernisporites macromanifestus* (Hacquebard) Utting, 1987a

GSC 89918, slide 4, 16.8 x 104.6, GSC loc. C-136340 (29.25 m).

Figure 19. *Cymbosporites acutus* (Kedo) Byvscheva, 1985

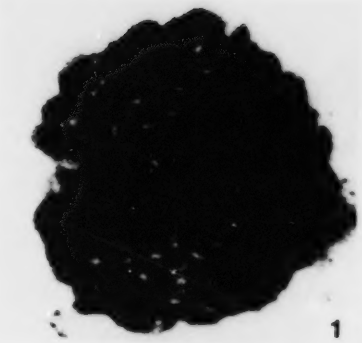
GSC 89915, slide 2, 25.5 x 100.7, GSC loc. C-146225.

Figure 20. *Dictyotriletes trivialis* Naumova in Kedo, 1963

GSC 89917, slide 3, 36.5 x 100.2, GSC loc. C-146220.

Figure 21. *Emphanisporites* sp. cf. *E. rotatus* McGregor, 1961

GSC 89922, slide 8, 35.4 x 109.2, GSC loc. C-146220.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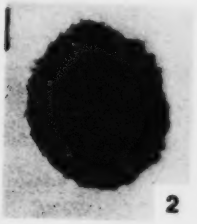
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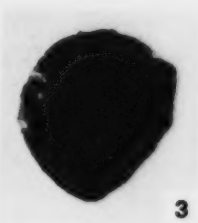
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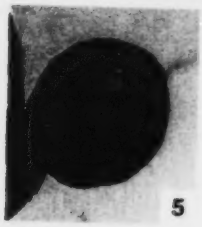
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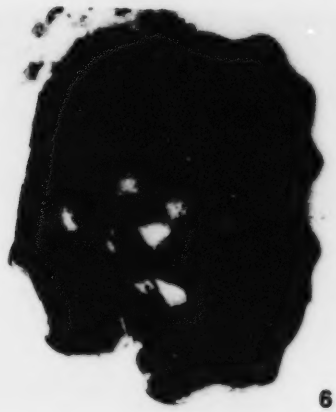
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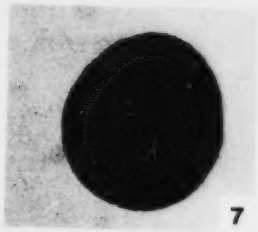
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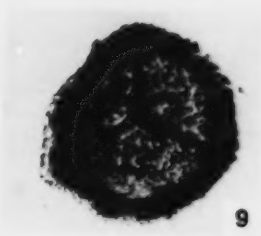
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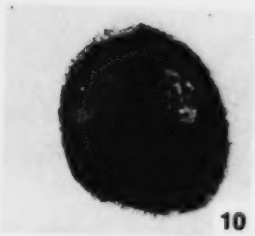
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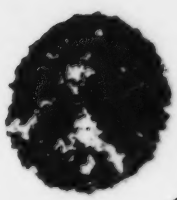
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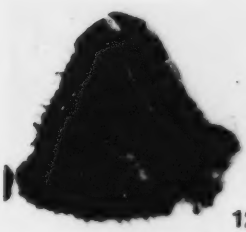
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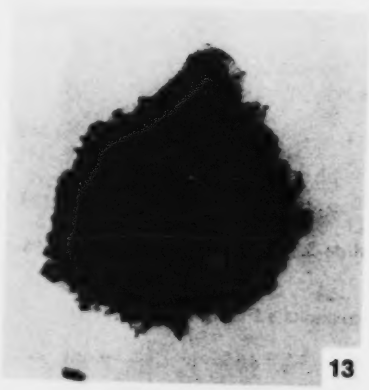
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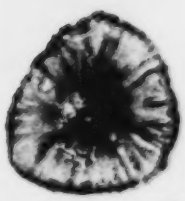
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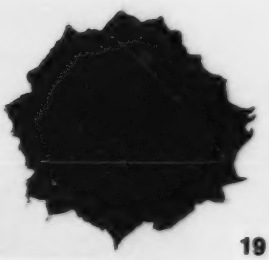
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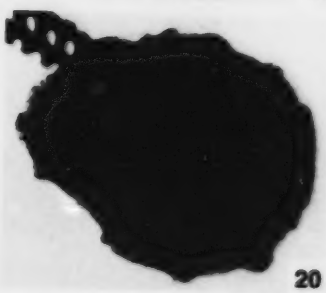
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PLATE 5.2

Figure 1. *Emphanisporites rotatus* McGregor, 1961

GSC 89923, slide 2, 29.3 x 107.0, GSC loc. C-146220.

Figure 2. *Granulatisporites crenulatus* Playford, 1964

GSC 89925, slide 3, 21.5 x 97.2, GSC loc. C-136340 (100.0 m).

Figure 3. *Granulatisporites microgranifer* (Ibrahim) Potonié and Kremp, 1955

GSC 89926, slide 5, 12.1 x 103.8, GSC loc. C-146227 (73.15 m).

Figures 4, 7. *Hymenozonotriletes explanatus* (Luber) Kedo, 1963

4. GSC 89927, slide 2, 37.4 x 95.1, GSC loc. C-146225.

7. GSC 89928, slide 3, 36.6 x 101.5, GSC loc. C-146225.

Figure 5. *Leiotriletes ornatus* Ischenko, 1956

GSC 89931, slide 3, 36.0 x 98.0, GSC loc. C-140250.

Figure 6. *Grandispora uncata* (Hacquebard) Gupta, 1969

GSC 89924, slide 4, 41.6 x 101.2, GSC loc. C-136340 (37.75 m).

Figure 8. *Knoxisporites literatus* (Waltz) Playford, 1962

GSC 89929, slide 5, 45.1 x 96.2, GSC loc. C-146220.

Figure 9. *Latosporites* sp.

GSC 89930, slide 3, 33.0 x 97.4, GSC loc. C-146220.

Figure 10. *Leiotriletes* sp. A Utting

GSC 89932, slide 2, 38.8 x 95.0, GSC loc. C-146227 (73.15 m).

Figure 11. *Lophozonotriletes malevkensis* Naumova in Kedo, 1964

GSC 89934, slide 8, 31.6 x 93.3, GSC loc. C-146220.

Figure 12. *Leiozonotriletes insignitus* Hacquebard, 1957

GSC 89933, slide 4, 20.0 x 102.3, GSC loc. C-136340 (70.0 m).

Figure 13. *Microreticulatisporites hortonensis* Playford, 1964

GSC 89935, slide 10, 23.2 x 103.0, GSC loc. C-140250.

Figure 14. *Punctatisporites glaber* (Naumova) Playford, 1962

GSC 89938, slide 3, 37.9 x 102.1, GSC loc. C-136340 (37.75 m).

Figure 15. *Raistrickia clavata* Hacquebard, 1957

GSC 89942, slide 3, 16.2 x 101.4, GSC loc. C-136340 (100.0 m).

Figures 16-18. *Neoraistrickia logani* (Winslow) Coleman and Clayton, 1987

16. GSC 89936, slide 4, 16.1 x 94.5, GSC loc. C-136340 (51.0 m).

17. Detail of apical ornament of specimen shown in Figure 18 (x1000 approx.)

18. GSC 89937, slide 4, 41.6 x 95.5, GSC loc. C-136340 (51.0 m).

Figure 19. *Pustulatisporites gibberosus* (Hacquebard) Playford, 1964

GSC 89940, slide 3, 21.2 x 96.8, GSC loc. C-136340 (29.25 m).

Figure 20. *Raistrickia baculosa* Hacquebard, 1957

GSC 89941, slide 4, 24.1 x 97.2, GSC loc. C-136340 (60.5 m).

Figure 21. *Raistrickia corynoges* Sullivan, 1968

GSC 89943, slide 3, 45.6 x 102.2, GSC loc. C-146220.

Figure 22. *Retusotriletes avonensis* Playford, 1964

GSC 89944, slide 1, 42.0 x 107.8, GSC plant loc. 6407.

Figure 23. *Retusotriletes crassus* Clayton, in Clayton et al., 1980

GSC 89945, slide 2, 24.3 x 105.5, GSC loc. C-146225.

Figure 24. *Retusotriletes incohatus* Sullivan, 1964

GSC 89946, slide 3, 18.5 x 108.0, GSC loc. C-136340 (37.75 m).

Figure 25. *Raistrickia ponderosa* Playford, 1964

GSC 89947, slide 4, 19.1 x 106.0, GSC loc. C-136340 (108.0 m).

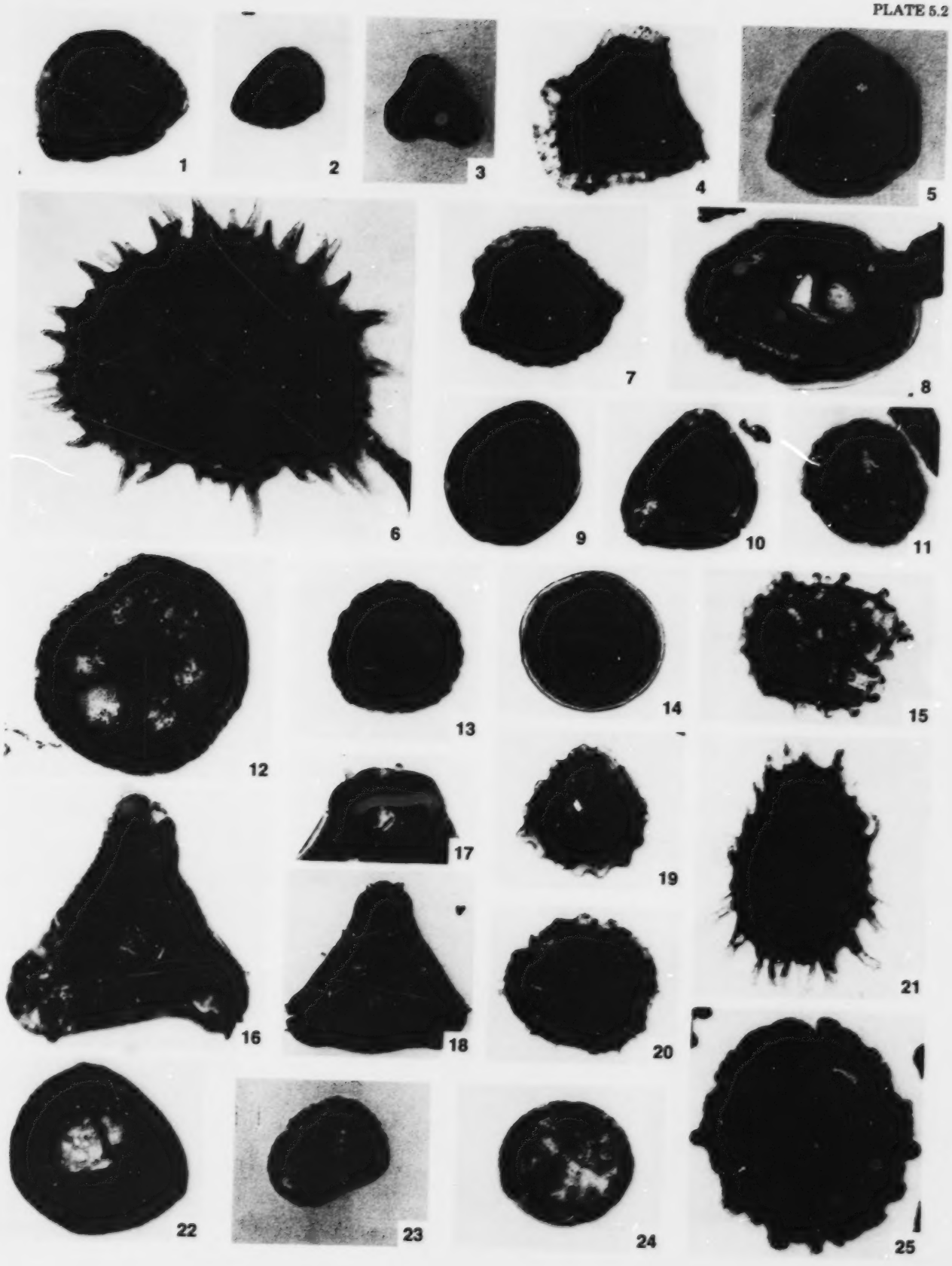
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PLATE 5. 3

Figure 1. *Punctatisporites irrasus* Hacquebard, 1957

GSC 89939, slide 10, 28.4 x 99.8, GSC loc. C-140250.

Figure 2. *Retusotriletes triangulatus* (Streel) Streel

GSC 89948, slide 5, 36.2 x 93.1, GSC loc. C-146227 (73.15 m).

Figure 3. *Rugospora minuta* Neves and Ioannides, 1974

GSC 89949, slide 10, 9.0 x 104.0, GSC loc. C-140250.

Figure 4. *Schopfites claviger* Sullivan, 1968

GSC 89952, slide 10, 8.9 x 93.2, GSC loc. C-140250.

Figure 5. *Rugospora polyptycha* Neves and Ioannides, 1974

GSC 89950, slide 2, 32.0 x 111.4, GSC loc. C-140250.

Figure 6. *Schopfites augustus* Playford, 1964

GSC 89951, slide 4, 14.5 x 95.6, GSC loc. C-136340, (29.25 m).

Figure 7. *Schopfites delicatus* Higgs, 1975

GSC 89953, slide 3, 24.5 x 95.2, GSC loc. C-140203.

Figures 8-13, 15. *Spelaeotriletes cabotii* sp. nov. Utting

8. GSC 89954, slide 7, 12.7 x 94.3, holotype, GSC loc. C-146224.

9. GSC 89955, slide 7, 19.1 x 109.4, GSC loc. C-146224.

10. GSC 89956, slide 7, 37.0 x 93.7, GSC loc. C-146224.

11. GSC 89957, slide 7, 36.6 x 97.0, GSC loc. C-146224.

12. GSC 89958, slide 7, 13.2 x 102.0, GSC loc. C-146224.

13. GSC 89959, slide 7, 11.1 x 107.8, GSC loc. C-146224.

15. GSC 89960, slide 7, 27.1 x 93.8, GSC loc. C-146224.

Figures 14, 16. *Spelaeotriletes echinatus* (Hacquebard) Utting, 1987a

14. GSC 89961, slide 10, 25.0 x 99.6, GSC loc. C-140250.

16. GSC 89962, slide 4, 13.1 x 94.1, GSC loc. C-140203.

Figures 17, 18. *Spelaeotriletes pretiosus* (Playford) Neves and Belt var. *pretiosus*

17. GSC 89963, slide 1, 28.6 x 93.5, GSC plant loc. 6407.

18. GSC 89964, slide 1, 33.4 x 106.5, GSC plant loc. 6407.

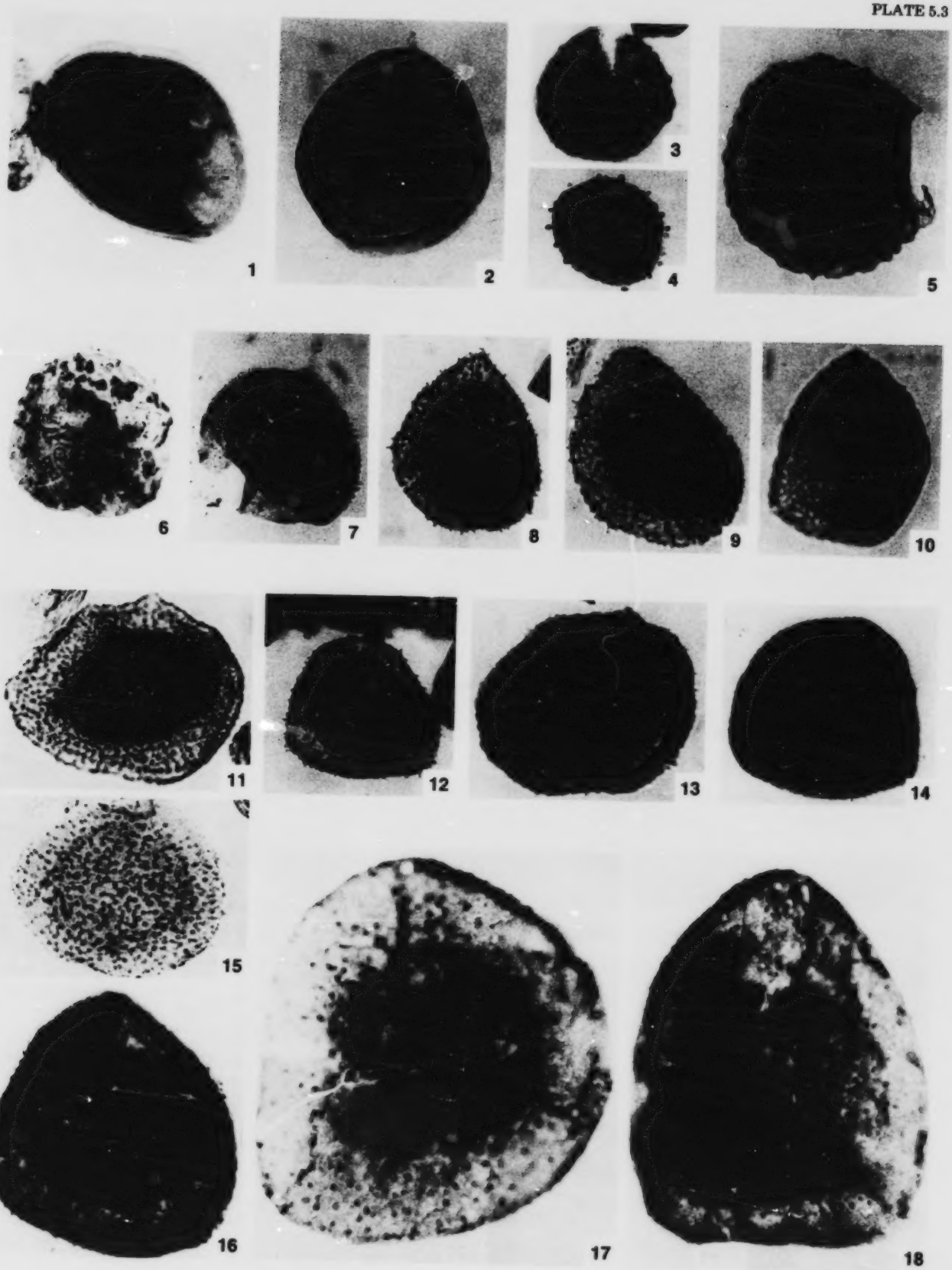
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PLATE 5.4

Figures 1, 2. *Spelaeotriletes pretiosus* (Playford) Neves and Belt var. *pretiosus*

1. GSC 89965, slide 1, 16.1 x 106.8, GSC plant loc. 6407.

2. GSC 89966, slide 1, 38.6 x 112.0, GSC plant loc. 6407.

Figure 3. *Spelaeotriletes pretiosus* (Playford) Neves and Belt var. *bellii* Utting, 1987a

GSC 89967, slide 1, 32.8 x 100.0, GSC plant loc. 6407.

Figure 4. *Umbonatisporites abstrusus* (Playford) Clayton, 1971

GSC 89968, slide 3, 32.7 x 96.8, GSC loc. C-136340 (51.0 m).

Figures 5, 6. *Umbonatisporites distinctus* Clayton, 1971

5. GSC 89969, slide 3, 37.2 x 97.4, GSC loc. C-136340, (75.0 m).

6. GSC 89970, slide 8, 35.2 x 101.2, GSC loc. C-146220.

Figures 7, 8. *Vallatisporites vallatus* Hacquebard, 1957

7. GSC 89972, slide 3, 38.7 x 101.6, GSC loc. C-136340 (29.25 m).

8. GSC 89973, slide 10, 5.6 x 97.0, GSC. loc. C-140250.

Figure 9. *Verrucosisporites congestus* Playford, 1964

GSC 89975, slide 3, 17.7 x 108.4, GSC loc. C-136340 (84.0 m).

Figures 10, 14. *Verrucosisporites nitidus* Playford, 1964

10. GSC 89977, slide 8, 31.5 x 105.1, GSC loc. C-146220.

14. GSC 89976, slide 7, 34.5 x 107.0, GSC loc. C-146224.

Figure 11. *Verrucosisporites papulosus* Hacquebard, 1937

GSC 89978, slide 7, 18.0 x 104.5, GSC loc. C-146220.

Figure 12. *Vallatisporites ciliaris* (Luber) Sullivan, 1964

GSC 89971, slide 2, 43.6 x 96.2, GSC loc. C-140250.

Figure 13. *Vallatisporites verrucosus* Hacquebard, 1937

GSC 89974, slide 5, 20.9 x 105.8, GSC loc. C-146227 (73.15 m).

Figures 15, 16, 18, 19. *Michrystridium* sp. (reworked?)

15. GSC 89980, slide 3, 40.2 x 94.6, GSC loc. C-136308.

16. GSC 89982, slide 3, 9.2 x 102.5, GSC loc. C-136307.

18. GSC 89983, slide 5, 42.4 x 99.1, GSC loc. C-78244.

19. GSC 89981, slide 3, 32.2 x 106.2, GSC loc. C-136308.

Figure 17. *Veryhachium europaeum* Stockmans and Willière, 1962 (reworked?)

GSC 87189, slide 3, 14.4 x 96.1, GSC loc. C-136308.

Figure 20. *Pterospermella* sp. (reworked?)

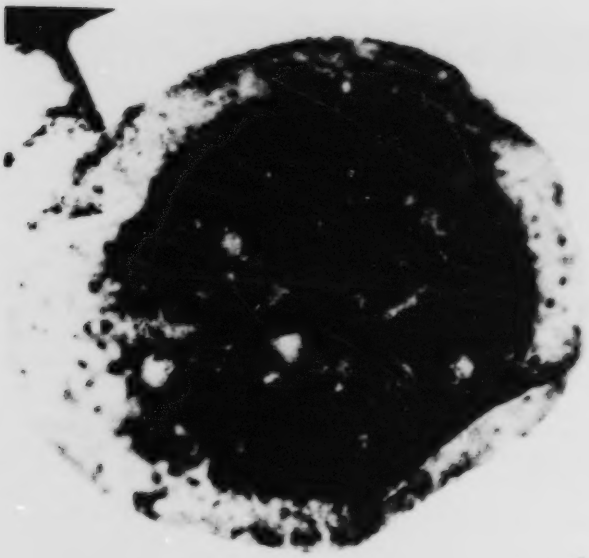
GSC 87187, slide 3, 16.7 x 104.0, GSC loc. C-136307.

Figure 21. *Veryhachium downiei* Stockmans and Willière, 1962 (reworked)

GSC 87188, slide 3, 41.6 x 108.5, GSC loc. C-136307.

Figure 22. *Diexallophasis remota* (Deunff) Playford, 1977 (reworked?)

GSC 89979, slide 2, 32.4 x 95.1, GSC loc. C-136350.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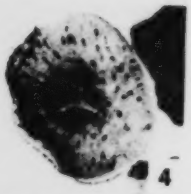
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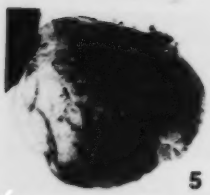
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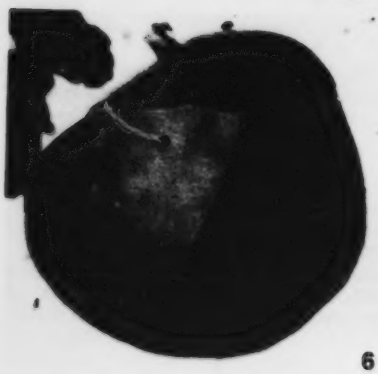
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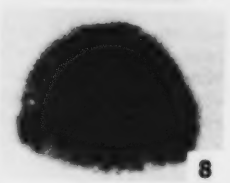
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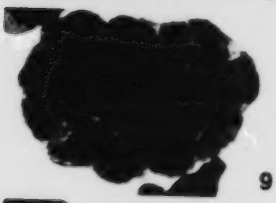
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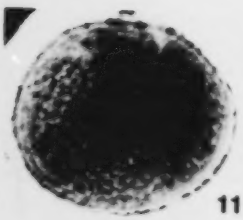
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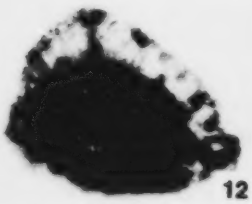
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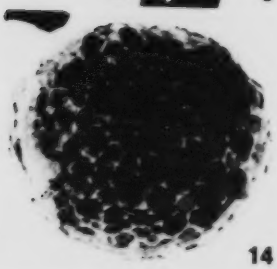
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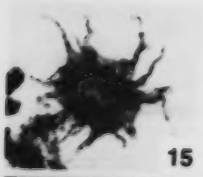
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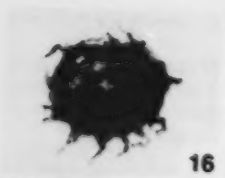
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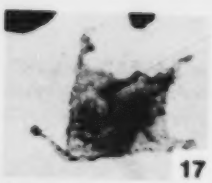
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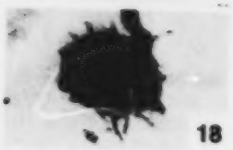
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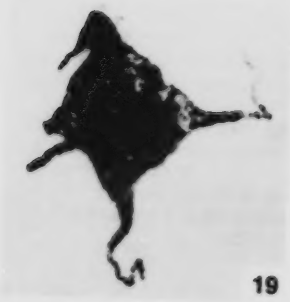
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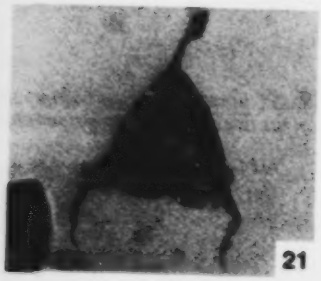
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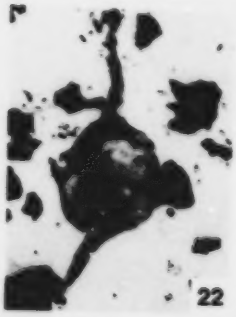
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PALYNOLOGY OF THE LOWER CARBONIFEROUS EMMA FIORD FORMATION OF DEVON, AXEL HEIBERG, AND ELLESMERE ISLANDS, CANADIAN ARCTIC ARCHIPELAGO

J. Utting[1], M. Jachowicz[2], and A. Jachowicz[2]*

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Abstract

Well preserved diverse miospore assemblages occur in the essentially lacustrine Emma Fiord Formation at the southeastern margin of the Sverdrup Basin on Grinnell Peninsula, Devon Island. Stratigraphically significant species include *Colatisporites decorus, Diatomozonotriletes saetosus, Knoxisporites stephanephorus, K. triradiatus, Lycospora pusilla, Murospora aurita, Perotrilites tessellatus, Rotaspora fracta, Spelaeotriletes arenaceus,* and *Waltzispora planiangulata.* Common genera are *Calamospora, Colatisporites, Lycospora,* and *Punctatisporites,* and the alga *Botryococcus.* One new species, *Cristatisporites apisaculeus,* is described.

In the northeastern part of the basin at Kleybolte Peninsula, Ellesmere Island, where the type section is located, and at Svartevaeg Cliffs, Axel Heiberg Island, a dominantly fluviatile facies of the formation contains similar, but less diverse assemblages, which have been thermally altered. These assemblages are dominated by cingulate taxa, including *Cingulizonates bialatus, Densosporites* spp., *Murospora aurita* and *Lycospora pusilla.*

Comparison with material from Western Canada (Mattson Formation and Stoddart Group) suggests a late Viséan (V_3) age for the Emma Fiord Formation. In spite of the fact that Arctic Canada and Western Europe belonged to two different floral provinces in the Viséan, approximate palynostratigraphic correlations can be made. It would appear that the Emma Fiord assemblages fall within the range of the *Raistrickia nigra-Triquitrites marginatus* (NM) Zone to possibly the *Tripartites vetustus-Rotaspora fracta* (VF) Zone of late Viséan (V_3) age.

The Thermal Alteration Index of spores is low on Grinnell Peninsula (TAI 2-, on a five-point scale), indicating a potential for liquid hydrocarbons. However, along the northeastern margin of Sverdrup Basin, on Axel Heiberg Island and northern Ellesmere Island, thermal alteration is high (TAI 4- to 5), within, or beyond, the preservation limit for dry gas.

Résumé

Divers assemblages de miospores bien conservés se trouvent dans la formation d'Emma Fiord, formation de nature essentiellement lacustre dans la marge sud-est du bassin de Sverdrup dans la presqu'île Grinnell (île Devon). Les espèces stratigraphiquement importantes sont notamment *Colatisporites decorus, Diatomozonotriletes saetosus, Knoxisporites stephanephorus, K. triradiatus, Lycospora pusilla, Murospora aurita, Perotrilites tesselatus, Rotaspora fracta, Spelaeotriletes arenaceus* et *Walzispora planiangulata.* Les genres communs sont *Calamospora, Colatisporites, Lycospora* et *Punctatisporites,* et l'algue *Botryococcus.* Une nouvelle espèce, *Cristatisporites apisaculeus,* est décrite.

Dans la partie nord-est du bassin de la presqu'île Kleybolte dans l'île d'Ellesmere, soit à emplacement du stratotype, et dans les falaises Svartevaeg de l'île Axel Heiberg, un faciès principalement fluviatile de la formation contient des assemblages semblables mais moins divers ayant subi une altération thermique. Ces assemblages sont surtout composés de taxons à cingularia notamment *Cingulizonates bialatus, Densosporites* spp., *Murospra aurita* et *Lycospora pusilla.*

La comparaison de ces assemblages à certains de l'Ouest canadien (formation de Mattson et groupe de Stoddart), permet d'avancer que la formation d'Emma Fiord remonte au Viséen supérieur (V_3).

Malgré le fait que l'Arctique canadian et l'Europe de l'Ouest faisaient partie de deux provinces florales différentes au Viséen, on peut néanmoins établir des corrélations palynostratigraphiques approximatives. Il semblerait que les assemblages d'Emma Fiord feraient partie de la série de la zone à *Raistrickia nigra-Triquitrites marginatus* (NM) et même peut-être de la zone à *Tripartites vetustus-Rotaspora fracta* (VF) du Viséen (V_3) supérieur.

L'indice d'altération thermique des spores est faible dans la presqu'île Grinnell (IAT 2-, sur une échelle à cinq points) indiquant un potentiel en formation d'hydrocarbures liquides. Cependant, le long de la marge nord-est du bassin de Sverdrup, dans l'île Axel Heiberg et dans le nord de l'île d'Ellesmere, l'indice d'altération thermique est élevé (IAT de 4- à 5), à l'intérieur et à l'extérieur de la limite de conservation de gaz sec.

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*Dr. A. Jachowicz, Vice-President of the University of Silesia, passed away on August 15th, 1989. Dr. Jachowicz will be remembered for his valuable contribution to the field of palynology.

REGIONAL STRATIGRAPHY

The oldest known rocks in Sverdrup Basin belong to the Emma Fiord Formation (Thorsteinsson, 1974), which is of Carboniferous age. The formation, which outcrops at a number of localities along the northern and southern margins of the present outcrop limit of Sverdrup Basin (Fig. 6.1) comprises two main facies. In the northern outcrops (Figs. 6.2, 6.3, 6.4), there are up to 400 m of conglomerate, sandstone, siltstone, mudstone, shale and thin coal beds, and in the south (Figs. 6.2, 6.5), there are up to 135 m of black carbonaceous shale, thin coal beds, siltstone and marlstone with interbedded sandstone, conglomerate and oolitic and algal limestone (Davies and Nassichuk, 1988). The type section (Fig. 6.1, locality 4; Fig. 6.3) is located on Kleybolte Peninsula at the northwestern extremity of Ellesmere Island; here the formation consists of 384 m of dark grey to black, thin to medium bedded, argillaceous and carbonaceous siltstone, with minor silty and carbonaceous shale, quartzose sandstone, quartzite-pebble conglomerate and thin coal seams (Davies and Nassichuk, 1988, Fig. 6.3). It lies with angular unconformity on deformed Devonian or older rocks of the Franklinian Geosynclinal succession and is overlain disconformably by conglomerates and sandstones of the Lower Carboniferous Borup Fiord Formation. Further outcrops on Ellesmere Island include approximately 50 m of black, fine grained, shaly greywacke on a nunatak near the head of Clements Markham Glacier (Christie, 1964, and Mayr, pers. comm.; Fig. 6.1, locality 7), and at least 60 m of conglomerate and dark grey siltstone interbedded with minor sandstone and shale in a nunatak at the head of the M'Clintock Glacier (Fig. 6.1, locality 6). In the latter, the lower boundary is an angular unconformity with rocks of the Franklinian geosyncline (Mayr, pers. comm.).

In the area around Parker Bay and Cape Hecla, northern Ellesmere Island, 700 m of interbedded siltstone and sandstone with minor shale and limestone have been recently assigned to the Emma Fiord Formation (Mayr, pers. comm.; Fig. 6.1, locality 8). These sediments had previously been included in the Sail Harbour Group, a mappable unit defined by Blackadar (1954), comprising Silurian to Carboniferous rocks belonging to both the Franklinian Mobile Belt and Sverdrup Basin.

On Axel Heiberg Island the Emma Fiord Formation outcrops at Svartevaeg Cliffs in the northeast (Fig. 6.1, locality 5; Fig. 6.5). The section described by Kerr and Trettin (1962) comprises quartzose sandstone and siltstone, and carbonaceous black shale, overlying, with angular unconformity, the deformed rocks of the Franklinian geosyncline. Three coal seams, each almost 1.0 m thick, were reported by Thorsteinsson (1974) from the lower 30 m of what he estimated to be approximately 120 m of section.

On Grinnell Peninsula, Devon Island (Fig. 6.1, localities 1-3), outcrops of the Emma Fiord Formation were first described from the Lyall River area by Kerr (1976); the formation was subsequently described by Davies and Nassichuk (1988). Here the formation, which is approximately 135 m thick (Fig. 6.5), lies with angular unconformity on Silurian limestones of the Cape Storm Formation. The rocks consist mainly of recessive marlstone

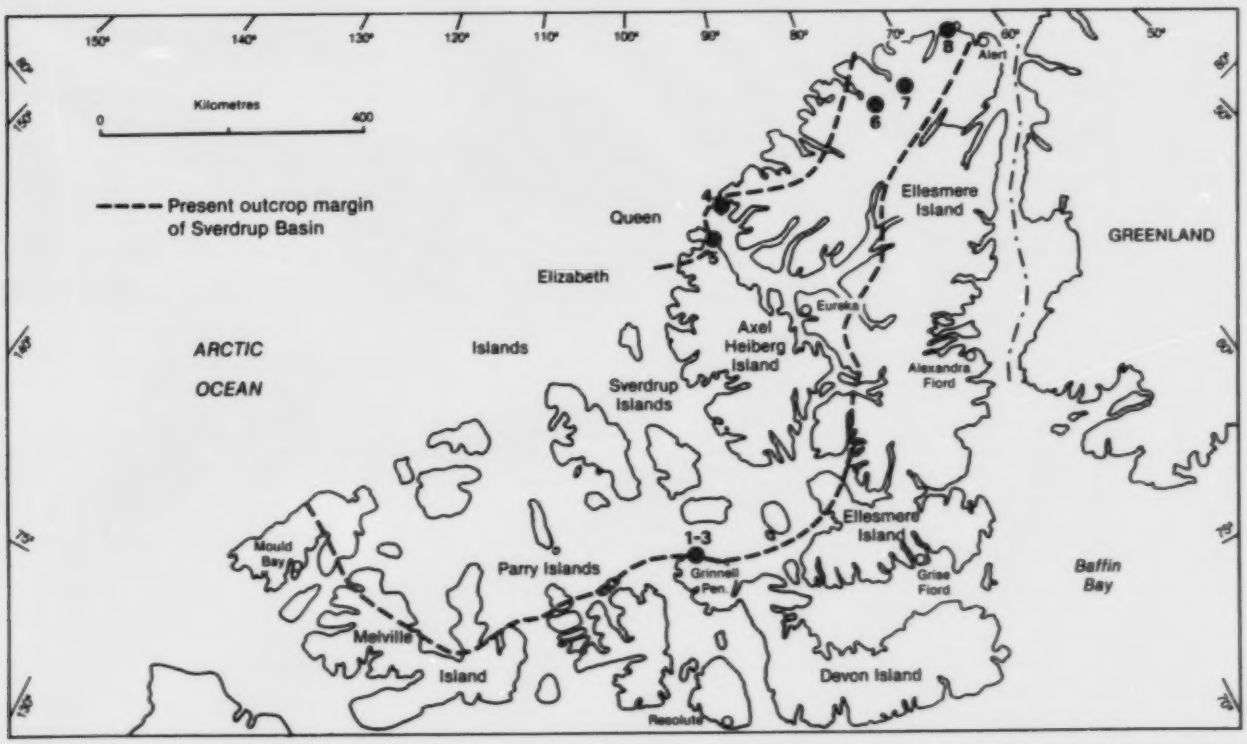

Figure 6.1. *Outcrop limits of Sverdrup Basin (modified from Nassichuk and Wilde, 1977) and location of Emma Fiord Formation outcrops. 1-3. Lyall River, Grinnell Peninsula, Devon Island; 4. type section of Emma Fiord Formation, Kleybolte Peninsula, Ellesmere Island; 5. Svartevaeg Cliffs, Axel Heiberg Island; 6. nunatak at head of M'Clintock Glacier, Ellesmere Island; 7. nunatak at head of Clements Markham Glacier, Ellesmere Island; 8. calcareous lithofacies around Parker Bay and Cape Hecla of the (?)Emma Fiord Formation, Ellesmere Island.*

and black carbonaceous and calcareous shale, with more resistant interbeds of oolitic and algal limestone and conglomerate characterized by an abundance of lacustrine algal clasts (Davies and Nassichuk, 1988); the formation is overlain disconformably by the Upper Carboniferous Canyon Fiord Formation.

PREVIOUS BIOSTRATIGRAPHIC WORK

Fossils recorded from the Emma Fiord Formation include ostracodes, small pelecypods, calcareous serpulid worm tubes, fish scales, phosphatic bone fragments from small vertebrates, algae, macroplants and palynomorphs (Nassichuk et al., 1986). At Svartevaeg Cliffs, northeastern Axel Heiberg Island, the following Lower Carboniferous macroplants are found: *Lepidodendron volkmannianum* Sternberg, *Knorria* sp. (lepidodendroid form), *Cyclopteris frondosa* Goeppert = *Cardiopteris frondosa* (Goeppert) Schimper, and *Rhodea tenuis* Gothan (Hueber in Playford and Barss, 1963). At Clements Markham nunatak section, northern Ellesmere Island, the flora includes: *Lepidodendropsis* sp., *L. corrugatum* (Dawson), *Asterocalamites scrobiculatus* Schlotheim, *Rhodea tenuis* Gothan, *Rhacopteris* sp., *Lepidodendron volkmannianum* Sternberg, *Sphenopteris* sp. (Hueber, in Christie, 1964). At Kleybolte Peninsula, northwestern Ellesmere Island, 40 m

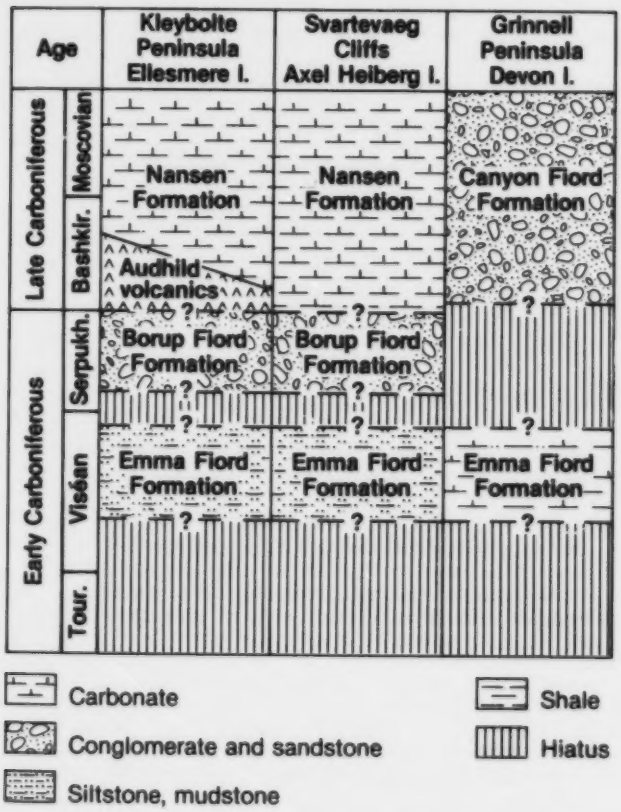

Figure 6.2. Stratigraphic sequence and correlations for lower to middle Upper Carboniferous succession on Kleybolte Peninsula, Ellesmere Island; Svartevaeg Cliffs, Axel Heiberg; and Grinnell Peninsula, Devon Island. (Modified from Davies and Nassichuk, 1988.)

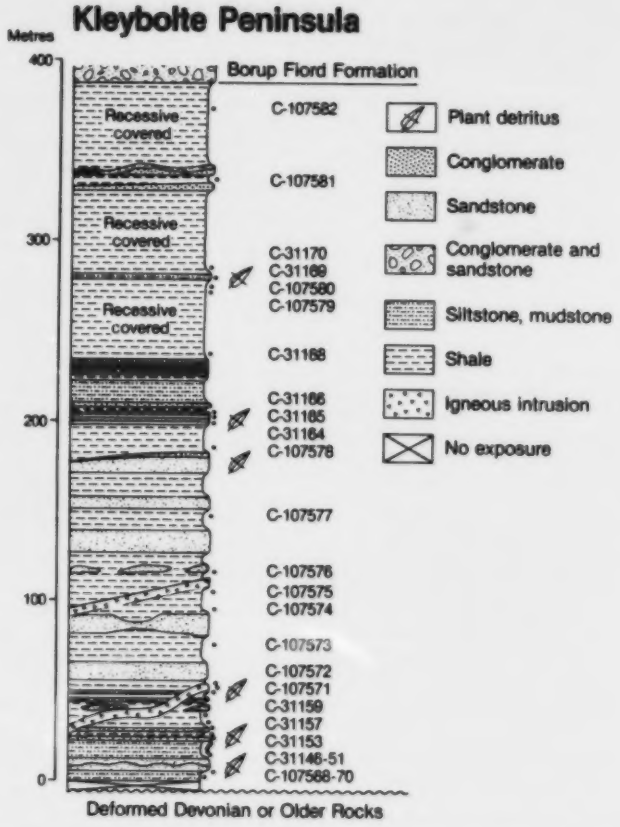

Figure 6.3. Sample localities in type section of Emma Fiord Formation, Kleybolte Peninsula, Ellesmere Island. (Modified from Davies and Nassichuk, 1988.)

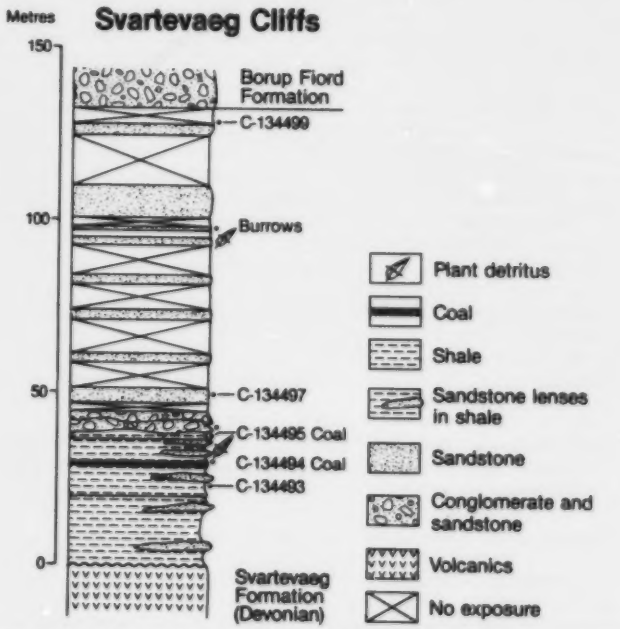

Figure 6.4. Sample localities in Svartevaeg Cliffs section, Axel Heiberg Island. (B.D. Ricketts, pers. comm.)

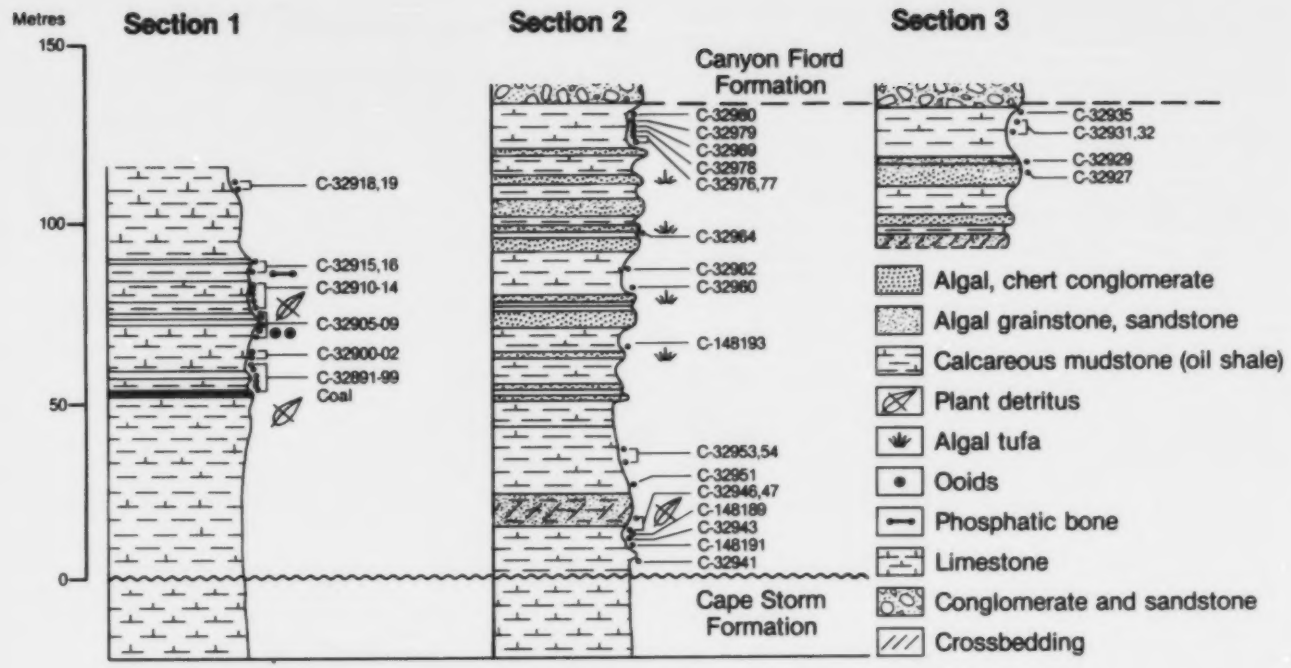

Figure 6.5. *Sample localities of three sections in the Lyall River area, Grinnell Peninsula, Devon Island. (Modified from Davies and Nassichuk, 1988.)*

above the base of the formation, *Cardiopteris abbensis* Read occurs, which indicates a Viséan age (Bell, in Thorsteinsson, 1974). Plants from Grinnell Peninsula, Devon Island, include *Stigmaria ficoides*, *Lepidostrobophyllum* sp. cf. *Cardiopteridium* sp. and lycopod twigs; the flora is similar to that of Spitsbergen, and is of Tournaisian to early Viséan age (Pfefferkorn, in Nassichuk, et al., 1986).

Miospores identified in a single sample from the Svartevaeg Cliffs by Playford and Barss (1963), include:

Anulatisporites anulatus (Loose) Potonié and Kremp, 1954 = *Densosporites anulatus* (Loose) Smith and Butterworth, 1967

Calamospora microrugosa (Ibrahim) Schopf, Wilson, and Bentall, 1944

Camptozonotriletes velatus (Waltz) Playford, 1963

Convolutispora cf. *clavata* (Ischenko) Hughes and Playford, 1961

Convolutispora tuberculata (Waltz) Hoffmeister, Staplin, and Malloy, 1955

Densosporites bialatus (Waltz) Potonié and Kremp, 1956 = *Cingulizonates bialatus* (Waltz) Smith and Butterworth, 1967

Densosporites dentatus (Waltz) Potonié and Kremp, 1956

Densosporites rarispinosus Playford, 1963

Diatomozonotriletes saetosus (Hacquebard and Barss) Hughes and Playford, 1961

Knoxisporites literatus (Waltz) Playford, 1963

Leiotriletes inermis (Waltz) Ishchenko, 1952

Lycospora uber (Hoffmeister, Staplin, and Malloy) Staplin, 1960 = *Lycospora pusilla* (Ibrahim) Schopf, Wilson, and Bentall, 1944

Murospora aurita (Waltz) Playford, 1962

Murospora intorta (Waltz) Playford, 1962

Murospora sublobata (Waltz) Playford, 1962

Punctatisporites glaber (Naumova) Playford, 1962

Reticulatisporites cancellatus (Waltz) Playford, 1962

Quantitatively the most important species are *Cingulizonates bialatus*, *Lycospora uber*, and *Murospora aurita*.

An almost identical assemblage of Viséan age was recorded by M.S. Barss (in Thorsteinsson, 1974) from a sample from the type section on Kleybolte Peninsula, at the same horizon where W.A. Bell recorded *Cardiopteris abbensis*.

Identifications include:

Anulatisporites anulatus (Loose) Potonié and Kremp, 1954 = *Densosporites anulatus* (Loose) Smith and Butterworth, 1967

Convolutispora clavata (Ishchenko) Hughes and Playford, 1961

Convolutispora tuberculata (Waltz) Hoffmeister, Staplin and Malloy, 1955

Densosporites bialatus (Waltz) Potonié and Kremp, 1956 = *Cingulizonates bialatus* (Waltz) Smith and Butterworth, 1967

Densosporites rarispinosus Playford, 1963

Lycospora uber (Hoffmeister, Staplin, and Malloy) Staplin, 1960 = *Lycospora pusilla* (Ibrahim) Schopf, Wilson, and Bentall, 1944

Lophozonotriletes appendices (Hacquebard and Barss) Playford, 1962

Microreticulatisporites lunatus Staplin, 1960

Murospora aurita (Waltz) Playford, 1962

Murospora sublobata (Waltz) Playford, 1962

Reticulatisporites cf. *rudis* Staplin, 1960

Reticulatisporites peltatus Playford, 1962 = *Cordylosporites papillatus* (Naumova) Playford and Satterthwait, 1985

Barss and McGregor (in Kerr, 1976) examined Viséan miospores from the Lyall River area of Grinnell Peninsula. Later, Barss (in Nassichuk and Davies, 1980) stated that the material was similar to that of the *Aurita* assemblage, which Playford (1962, 1963) described from Spitsbergen, and which was assigned a Viséan to possibly Namurian age. However, the index species of the *Aurita* assemblage (*Murospora aurita*) was not seen in the samples studied. Barss noted the presence of *Knoxisporites stephanephorus*, *Knoxisporites triradiatus* and *Secarisporites remotus*. These species had not previously been found in either the Svartevaeg or the Kleybolte Peninsula material.

Nassichuk et al. (1986) provided strong evidence to suggest a lacustrine environment of deposition for the Emma Fiord Formation. The evidence they cited includes: lack of marine fossils; abundance of terrestrial plant debris, coal, spores and pollen; abundance of tufa-like carbonate clasts and cement analogous to those occurring in lacustrine tufas in Quaternary lakes of the western and southwestern United States; and ooid grainstone similar to the ooid grainstone of the Great Salt Lake, Utah, and other ephemeral Quaternary lake systems. Additional evidence for a nonmarine origin includes a significant ^{13}C isotopic depletion in the Emma Fiord carbonates (B. Beauchamp, pers. comm., 1988), contrasting markedly with all upper Paleozoic marine sediments of Sverdrup Basin, which are characteristically enriched in ^{13}C (Beauchamp et al., 1987).

Paleontological information from the unit referred to as (?) Emma Fiord on northern Ellesmere Island is limited (Mayr, in preparation). Mayr collected poorly preserved ostracodes (GSC loc. C-070185) from a talus sample and these were dated as Paleozoic (Copeland, pers. comm. to Mayr, 1978). From a single talus sample collected by Mayr, the following conodont species were identified by A.C. Higgins (pers. comm., 1986): *Paragnathodus commutatus* (Branson and Mehl, 1941), *Vogelgnathus campbelli* (Rexroad, 1957) and a new genus and species. Higgins proposed an age within the Chester Stage, equivalent to the late Viséan-early Namurian. Thus, the so-called Emma Fiord Formation on northern Ellesmere Island could potentially be a facies equivalent of the Borup Fiord Formation, as the latter yielded foraminifers of early Namurian age (Mamet, in Thorsteinsson, 1974).

PALYNOLOGICAL TECHNIQUES

Standard processing techniques similar to those described by Barss and Williams (1973) and summarized by Utting (1987b) were employed. The organic-rich oil shales from Grinnell Peninsula were given brief oxidation and ultrasonic (one minute) treatments. Thermally mature material from Kleybolte and Svartevaeg was treated for up to 12 hours with Schulze solution.

PRESERVATION OF PALYNOMORPHS

The preservation of the palynomorphs in the Emma Fiord Formation is variable throughout the study area. On northern Ellesmere and northeastern Axel Heiberg islands, the formation was deposited along the tectonically active northwestern rim of Sverdrup Basin. There is a considerable thickness of upper Paleozoic and Mesozoic sedimentary strata, intruded by numerous igneous bodies. These features resulted in the relatively high Thermal Alteration Index (TAI 4- to 5) on the five-point scale of Hunt (1979), Utting (1987a), and Utting et al. (in press). At the type section, Goodarzi et al. (1987), determined that the vitrinite reflectance is 5.0, and concluded that the rocks are overmature (beyond dry gas generation). In contrast, at the Grinnell locality, which is situated at the southern edge of Sverdrup Basin, and where there was probably only a thin cover of younger sediments (Fig. 6.1), the thermal maturity is low (TAI 2-), suggesting a potential for liquid hydrocarbon generation. The vitrinite reflectance at Grinnell Peninsula ranges from 0.26 at the top of the formation to 0.50 at the base (Goodarzi et al., 1987). The thin coal beds are subbituminous, and many of the argillaceous units are liptinite-rich sediments (torbanite) and may be classified as oil shales.

No identifiable palynomorphs were found in samples from the M'Clintock Glacier, northern Ellesmere Island (GSC locs. C-69919, C-69920, and C-69921), collected by U. Mayr from what is probably the lower 50 m of the outcrop, but the preparations contain black woody fragments, suggesting a high TAI. Nor were identifiable specimens found in samples from the 50 m thick nunatak section near Clements Markham Glacier (samples from GSC plant loc. 5806, collected by Hattersley-Smith; and GSC loc. C-83451, collected by U. Mayr). Black, circular to rounded triangular entities do occur; these are almost certainly miospores although no trilete mark is visible. A high TAI (4 to 5) is indicated. In the (?)Emma Fiord Formation, northeastern Ellesmere Island, thermal alteration is also high, with a conodont Colour Alteration Index (CAI) of 5 (Higgins, pers. comm.). This, on the scale of Epstein et al. (1977), would indicate a potential for dry gas (a CAI of 5 is approximately equivalent to a TAI of 4 to 5). No palynomorphs were found in samples from this group, although preparations do contain black woody and coaly fragments, also indicating a high TAI.

The vertical qualitative distribution of species for the Kleybolte, Svartevaeg and Grinnell samples is shown in Figure 6.6 and a composite list of taxa is given in Table 6.1. Figure 6.6 shows that, qualitatively, the assemblages from Grinnell are much more diverse than those from Kleybolte and Svartevaeg. This may be due to preservational differences; many specimens in both the Kleybolte and Svartevaeg localities cannot be identified with confidence as they remain black even after oxidation. There are, nevertheless, some fundamental differences, which are discussed below.

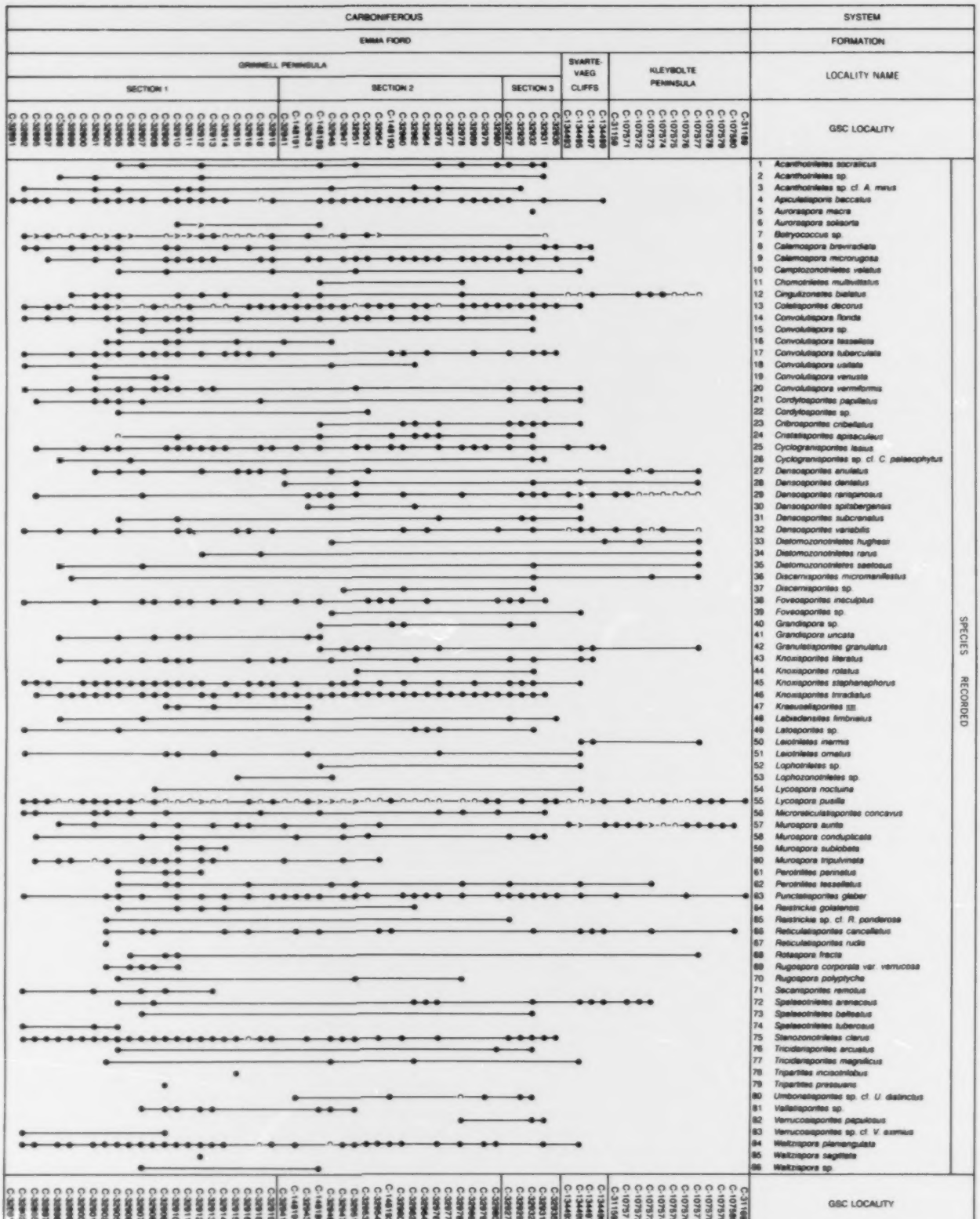

Figure 6.6. *Vertical distribution of miospore taxa in three sections of the Lyall River area, Grinnell Peninsula, Devon Island, in the section at Svartevaeg cliffs, Axel Heiberg Island, and in the type section of the Emma Fiord Formation, Kleybolte Peninsula, Ellesmere Island.* ● *= present (1-10); c = common (11-50); A = abundant (51+); 250 specimens counted.*

TABLE 6.1

Composite list of taxa present in the Emma Fiord Formation

TRILETES

Azonotriletes

Laevigati

Calamospora breviradiata Kosanke, 1950
Calamospora microrugosa (Ibrahim) Schopf, Wilson and Bentall, 1944
Leiotriletes inermis (Waltz) Ishchenko, 1952
Leiotriletes ornatus Ishchenko, 1956
Punctatisporites glaber (Naumova) Playford, 1962

Granulati

Cyclogranisporites lasius (Waltz) Playford, 1962
Cyclogranisporites sp. cf. *C. palaeophytus* Neves and Ioannides, 1974
Granulatisporites granulatus Ibrahim, 1933
Waltzispora planiangulata Sullivan, 1964
Waltzispora sagittata Playford, 1962
Waltzispora sp.

Apiculati

Acanthotriletes sp.
Acanthotriletes sp. cf. *A. minus* Ishchenko, 1956
Acanthotriletes socraticus Neves and Ioannides, 1974
Apiculatisporis baccatus Staplin, 1960
Tricidarisporites arcuatus Neville, 1973
Tricidarisporites magnificus Neville, 1973
Umbonatisporites sp. cf. *U. distinctus* Clayton, 1971

Baculati

Raistrickia golatensis Staplin, 1960
Raistrickia sp. cf. *R. ponderosa* Playford, 1964

Verrucati

Verrucosisporites sp. cf. *V. eximius* Playford, 1962
Verrucosisporites papulosus Hacquebard, 1957

Murornati

Camptotriletes velatus (Waltz) Playford, 1963
Convolutispora florida Hoffmeister, Staplin and Malloy, 1955
Convolutispora tessellata Hoffmeister, Staplin and Malloy, 1955
Convolutispora tuberculata (Waltz) Hoffmeister, Staplin and Malloy, 1955
Convolutispora usitata Playford, 1962
Convolutispora venusta Hoffmeister, Staplin and Malloy, 1955
Convolutispora vermiformis Hughes and Playford, 1961
Convolutispora sp.
Cordylosporites papillatus (Naumova) Playford and Satterthwait, 1985
Cordylosporites sp.
Foveosporites insculptus Playford, 1963
Foveosporites sp.
Microreticulatisporites concavus Butterworth and Williams, 1958

Pseudocingulati

Secarisporites remotus Neves, 1961

Zonotriletes

Auriculati

Tripartites pressuens (Ishchenko) Agrali and Kongali, 1969
Tripartites incisotrilobus (Naumova) Potonié and Kremp, 1956

Tricrassati

Diatomozonotriletes hughesii Playford, 1963
Diatomozonotriletes rarus Playford, 1963
Diatomozonotriletes saetosus (Hacquebard and Barss) Hughes and Playford, 1961

Cingulati

Knoxisporites literatus (Waltz) Playford, 1963
Knoxisporites rotatus Hoffmeister, Staplin and Malloy, 1955
Knoxisporites stephanephorus Love, 1960
Knoxisporites triradiatus Hoffmeister, Staplin and Malloy, 1955
Labiadensites fimbriatus (Waltz) Hacquebard and Barss, 1957
Lophozonotriletes sp.
Murospora aurita (Waltz) Playford, 1962
Murospora conduplicata (Andrejeva) Playford, 1962
Murospora sublobata (Waltz) Playford, 1962
Murospora tripulvinata Staplin, 1960
Reticulatisporites cancellatus (Waltz) Playford, 1962
Reticulatisporites rudis Staplin, 1960
Rotaspora fracta (Schemel) Smith and Butterworth, 1967
Stenozonotriletes clarus Ishchenko, 1958

Cingulicavati

Cingulizonates bialatus (Waltz) Smith and Butterworth, 1967
Cristatisporites apisaculeus sp. nov. Utting
Densosporites anulatus (Loose) Smith and Butterworth, 1967
Densosporites dentatus (Waltz) Potonié and Kremp, 1956
Densosporites rarispinosus Playford, 1963
Densosporites spitsbergensis Playford, 1963
Densosporites subcrenatus (Waltz) Potonié and Kremp, 1956
Densosporites variabilis (Waltz) Potonié and Kremp, 1956
Kraeuselisporites sp.
Lycospora noctuina Butterworth and Williams, 1958
Lycospora pusilla (Ibrahim) Schopf, Wilson and Bentall, 1944
Vallatisporites sp.

Zonati

Cribrosporites cribellatus Sullivan, 1964

Decorati

Perotrilites perinatus Hughes and Playford, 1961
Perotrilites tessellatus (Staplin) Neville, 1973
Rugospora corporata var. *verrucosa* Neville, 1968
Rugospora polyptycha Neves and Ioannides, 1974
Spelaeotriletes arenaceus Neves and Owens, 1966
Spelaeotriletes balteatus (Playford) Higgs, 1975
Spelaeotriletes tuberosus Utting, 1987

Membranatitriletes

Continuati

Discernisporites micromanifestus (Hacquebard) Sabry and Neves, 1971
Discernisporites sp.
Grandispora uncata (Hacquebard) Gupta, 1969
Grandispora sp.

Triletisacciti

Auroraspora macra Sullivan, 1968
Auroraspora solisorta Hoffmeister, Staplin and Malloy, 1955
Colatisporites decorus (Bharadwaj and Venkachatala) Williams, 1973

Monoletes

Latosporites sp.

Aletes

Chomotriletes multivittatus Playford, 1978

Chrysophyta

Xanthophyceae
Botryococcus sp.

STRATIGRAPHIC PALYNOLOGY

Description of assemblages

Assemblages from the Grinnell sections are qualitatively and quantitatively variable; they are commonly diverse, but some are dominated by only a few species, e.g., *Lycospora pusilla*, *Colatisporites decorus*, *Waltzispora planiangulata*. This variation appears to reflect alternating facies changes, rather than any evolutionary change in the palynoflora. Samples that contain abundant algal material (*Botryococcus* sp.) often lack diverse spore assemblages. The probable reason for this is twofold: first, there was difficulty in processing samples containing abundant amorphous organic matter (see Techniques). Not only was a smaller amount of rock chemically digested, but fewer spores were released from the entangled mass of amorphous debris. Secondly, abundance of amorphous material may be of environmental significance, and reflect algal growth in oxic, lacustrine surface waters (Utting, 1987b, p. 90), whereas rocks containing little amorphous material, but yielding abundant miospore assemblages, may have been deposited in a higher energy environment such as one close to the mouth of a river.

Several miospore species are common to most of the Grinnell samples (Fig. 6.6). These include *Apiculatisporis baccatus*, *Calamospora microrugosa*, *Colatisporites decorus*, *Convolutispora florida*, *Cyclogranisporites lasius*, *Foveosporites insculptus*, *Knoxisporites stephanephorus*, *K. triradiatus*, *Lycospora pusilla*, *Murospora tripulvinata*, *Punctatisporites glaber*, *Stenozonotriletes clarus* and *Waltzispora planiangulata*. Other species, which are biostratigraphically significant, but rare, include, *Camptozonotriletes velatus*, *Cingulizonates bialatus*, *Cordylosporites papillatus*, *Cribrosporites cribellatus*, *Densosporites rarispinosus*, *Diatomozonotriletes hughesii*, *Murospora aurita*, *Perotrilites tessellatus*, *Rotaspora fracta* and *Spelaeotriletes arenaceus*.

The Svartevaeg and Kleybolte sections, which were both deposited in a fluviatile environment, contain assemblages dominated quantitatively by cingulate genera (*Densosporites*, *Cingulizonates*, *Murospora* and *Lycospora*). The assemblages are essentially similar and of equivalent age. Some species present in Grinnell are lacking in Svartevaeg and Kleybolte; these include *Botryococcus* sp., *Cristatisporites apisaculeatus*, *Knoxisporites triradiatus*, *Murospora tripulvinata*, *Waltzispora planiangulata*, *Stenozonotriletes clarus*, and *Foveosporites insculptus*. The reasons for these differences are not yet clear. The Grinnell rocks are dominantly lacustrine but facies may not be the only reason for the assemblage differences. It is possible that there may be a slight age difference between the strata at the Kleybolte/Svartevaeg and Grinnell localities.

Paleoenvironment

Nassichuk et al. (1986), and Davies and Nassichuk (1988) suggested that the Emma Fiord Formation on Grinnell Peninsula was a lacustrine oil shale, probably deposited in an environment similar to that of the older Albert Formation of New Brunswick of Tournaisian (probably late Tn2 to early Tn3) age (Utting, 1987b). Both units have many samples containing abundant specimens of the freshwater alga *Botryococcus*, and at both localities, significant amounts of exinous, woody and coaly material indicate a nearby land source.

Rivers draining into the Emma Fiord lakes, and depositing their sediment load, would have disturbed the otherwise low energy lacustrine conditions, and introduced palynomorphs from the terrestrial hinterland. Locally derived miospores from lake shore vegetation might be expected to be dominant in the quieter lacustrine areas isolated from the direct influence of fluviatile input.

Corrosion of miospore exines by the growth of pyrite crystals was observed in some Grinnell samples, but not others, suggesting that at certain times in the lake's history, there were anoxic conditions in the bottom sediments.

At Svartevaeg and Kleybolte, the sediments consist predominantly of shale, cross-bedded sandstone and conglomerate; the oolitic algal limestone and calcareous mudstone typical of the Grinnell locality are absent. The environmental implications of these differences are not certain, but may, for the two northern localities, indicate proximity to a fluvial deltaic facies at a lake margin. The lack of the algal genus *Botryococcus* (common in some lacustrine facies), and the abundance of cingulate miospores at Kleybolte and Svartevaeg, may be environmentally significant. *Densosporites*, *Cingulizonates* and *Murospora*, with their heavy cingulate structure, would not be dispersed any great distance, but would settle close to their source. *Densosporites* is believed to be derived from a herbaceous lycopod (e.g., Chaloner, 1958). Thus deposition may well have occurred in a swamp, a deltaic or nearshore lacustrine environment. Habib et al. (1966), pointed out that in the Upper Carboniferous of western Pennsylvania, the abundance of *Densosporites* was a feature of marine shoreline sediments, but no marine sediments of Viséan age are known to occur near the Svartevaeg or Kleybolte sections.

The climate that existed at the time of deposition of the Emma Fiord Formation in the Grinnell Peninsula area was probably one with high temperatures and moderate seasonal rainfall (Davies and Nassichuk, 1988). However, abundance of *Densosporites* and *Murospora aurita*, such as occurs in the Svartevaeg and Kleybolte material may, according to Van der Zwan et al. (1985), indicate a humid environment in some areas. A warm humid climate is similar to that prevailing in the "*Lophozonotriletes* region" of Van der Zwan (1981) during the Tournaisian (Tn2) and Viséan (V_1); other areas in the "*Lophozonotriletes* region" include West Pomerania in Poland, the Donetz Basin and Pripyat Depression of the U.S.S.R., and Spitsbergen. Clayton (1985) included the mid-late Viséan assemblages from the Canadian Arctic in the *Monilospora* microflora, which he suggested originated in an equatorial to very low latitude position.

Stratigraphic correlation

The Kleybolte and Svartevaeg assemblages are very similar and were probably approximately coeval. Those from Grinnell are not the same and may be of a slightly different age, although certain assemblage differences, especially quantitative variations, are probably the result of a different depositional environment. The precise stratigraphic relationships of the Kleybolte/Svartevaeg and Grinnell assemblages cannot be resolved from the present data, but may in the future be determined by study of additional sections and further regional correlations.

A comparison with assemblages from other localities in northwest and Western Canada indicates general similarities between assemblages from the Emma Fiord material and those of Viséan age, yet to be studied in detail. For example, in northern Yukon in the Black Fox anticline (GSC loc.

C-138511), and at Hoidahl Dome (GSC locs. C-140217 and C-140218), the Kayak Formation contains some species also found in the Emma Fiord Formation (Bamber et al., 1989; Table 6.2). It is possible that this Yukon material, which contains marine palynomorphs (scolecodonts), is slightly older – lower to middle Viséan (V_1 to V_2) – than the Emma Fiord material.

Farther south, in southeastern Eagle Plain (Yukon), the upper part of the shallow marine Ford Lake Formation, and all but the uppermost part of the Hart River Formation, contain many species in common with those from the Emma Fiord Formation (Bamber et al., 1989; Table 6.2). These beds are of late Viséan (V_3) age and probably no older than the *Tripartites vetustus - Rotaspora fracta* (VF) Zone of Western Europe described by Clayton et al. (1977).

In southwestern District of Mackenzie, northeastern British Columbia, and northwestern Alberta, assemblages similar to the Emma Fiord occur in the Golata Formation (Staplin, 1960) and the lower and middle parts of the Mattson Formation (Braman and Hills, 1977); these are of late Viséan (V_3) age (Table 6.2). The material from the uppermost part of the Mattson is younger, Namurian in age (Utting, 1983). Work in progress by one of us (Utting) on the approximate subsurface equivalents of the Mattson Formation, the Stoddart Group, suggests that diverse assemblages similar to the Grinnell material occur in the Golata Formation, and less diverse assemblages similar to the Kleybolte and Svartevaeg material occur in the overlying Kiskatinaw Formation. This would suggest an approximate correlation with foraminifer Zone 15 and Zone 16 respectively, or a mid - late Viséan (V_3) age (Mamet and Skipp, in Richards et al., in press).

In Atlantic Canada (Fig. 6.7), the middle to late Viséan (V_2 to V_3) assemblages of the Upper Windsor Group, described by Utting (1980; 1987a) are lacking in diversity, but contain a few species in common with the Emma Fiord material (Table 6.2). However, in the Windsor Group, *Diatomozonotriletes*, *Murospora*, *Rotaspora* and *Waltzispora* are lacking, and there is a marked scarcity of cingulate

TABLE 6.2

Occurrence of stratigraphically important taxa

	1	2	3	4	5a	5b	6	7
Lycospora pusilla	X	X	X	X	X	X	X	X
Murospora aurita	X	X	X	X	X	X	X	
Rotaspora fracta	X	X		X		X	X	
Auroraspora solisorta	X				X	X	X	X
Colatisporites decorus	X	X		X	X	X	X	X
Knoxisporites literatus	X	X	X				X	X
K. stephanephorus	X	X				X	X	X
K. triradiatus	X				X		X	X
Perotrilites tessellatus	X	X			X	X	X	
Spelaeotriletes arenaceus	X	X		X	X	X	X	
Tripartites spp.	X		X	X	X	X	X	
Waltzispora planiangulata	X							
Densosporites anulatus	X	X	X	X	X	X	X	
D. rarispinosus	X	X	X	X	X	X	X	
Cingulizonates bialatus	X	X	X	X	X	X	X	
Diatomozonotriletes saetosus	X	X		X	X	X	X	
D. hughesii	X	X						

1. Emma Fiord Formation, Grinnell Peninsula, Devon Island.
2. Emma Fiord Formation, Kleybolte Peninsula, Ellesmere Island, and Svartevaeg Cliffs, Axel Heiberg Island.
3. Kayak Formation, northern Yukon (Utting, personal observation).
4. Upper Ford Lake Formation and Hart River Formation (excluding uppermost part), southeastern Eagle Plains, Yukon (Utting, personal observation).
5. Stoddart Group, northeastern British Columbia, northwestern Alberta and southwestern District of Mackenzie.

5a. Golata Formation.

5b. Kiskatinaw Formation (Staplin, 1960; Utting, personal observation).

6. Lower and middle parts of the Mattson Formation, Southwest District of Mackenzie and northeastern British Columbia (Braman and Hills, 1977; Utting, personal observation).
7. Windsor Group, Atlantic Canada (Utting, 1980; 1987a).

grains, such as *Densosporites*. However, the most striking differences are quantitative. The Windsor material is dominated by *Crassispora trychera* and *Rugospora minuta*, whereas these species are rare or absent in the Emma Fiord Formation. These major differences reflect the fact that, as suggested by the work of Sullivan (1965), Atlantic and Arctic Canada were in different floral provinces, the former containing the *Grandispora* microflora and the latter the *Monilospora* microflora (Sullivan, 1965; Clayton, 1985).

In the United States, the assemblages from the Hardinsburg Formation of Illinois and Kentucky, described by Hoffmeister et al. (1955), contain some species in common with the Emma Fiord material (Table 6.3). In the northeastern part of Kentucky (Ettensohn and Peppers, 1979) the uppermost part of the Glen Dean Member of the Newman Limestone, and the lower dark shale member of the Pennington Formation, of late Viséan age (V_3), contain few species similar to those in the Emma Fiord Formation (Table 6.3). In Tennessee, in the Warsaw and St. Louis formations, Neves (in Horowitz et al., 1979), reported assemblages that he considered to be approximately similar in age (late Viséan, V_3) to the *Perotrilites tessellatus - Schulzospora campyloptera* (TC) Zone of Western Europe. A number of species are common to the Emma Fiord material (Table 6.3), although *Murospora aurita* is absent. In general, the assemblages from the United States have more in common with material from Atlantic Canada (Utting, 1987a).

Correlation with assemblages outside North America indicates a close similarity between the Svartevaeg, Kleybolte and Grinnell material, and that of the Viséan of

TABLE 6.3

Comparison of occurrence of stratigraphically important taxa in the Emma Fiord Formation, Canadian Arctic, with areas in North America, Western Europe and U.S.S.R.

	1	2	3	4	5	6	7	8	9	10
Lycospora pusilla	X	X	X	X	X	X	X	X	X	X
Murospora aurita	X	X				X		X	X	
Rotaspora fracta	X	X	X				X	X		
Auroraspora solisorta	X		X		X		X			
Colatisporites decorus	X	X			X		X			
Knoxisporites literatus	X	X				X	X	X	X	X
K. stephanephorus	X	X			X		X	X		
K. triradiatus	X		X	X	X		X			
Perotrilites tessellatus	X	X				X	X	X		
Spelaeotriletes arenaceus	X	X								
Tripartites spp.	X		X		X	X	X	X	X	
Waltzispora planiangulata	X						X			
Densosporites anulatus	X	X			X	X	X			
D. rarispinosus	X	X				X				
Cingulizonates bialatus	X	X		X		X	X		X	X
Murospora tripulvinata	X					X			X	
Cribrosporites cribellatus	X						X			
Diatomozonotriletes saetosus	X	X				X	X		X	
D. hughesii	X	X				X				
Tricidarisporites magnificus	X	X					X			

1. Emma Fiord Formation, Grinnell Peninsula, Devon Island.
2. Emma Fiord Formation, Kleybolte Peninsula, Ellesmere Island, and Svartevaeg Cliffs, Axel Heiberg Island.
3. Viséan Hardinsburg Formation, Illinois and Kentucky (Hoffmeister, 1955).
4. Late Viséan dark shale member and the upper clastic member of the Pennington Formation, Kentucky (Ettensohn and Peppers, 1979).
5. Viséan St. Louis and Warsaw formations, Tennessee (Horowitz et al., 1979).
6. Viséan of Spitsbergen (Playford, 1962, 1963).
7. Viséan of Western Europe, (Neves et al., 1973; Clayton et al., 1977).
8. Viséan Donetz Basin, U.S.S.R. (Owens et al., 1978).
9. Bobrikov (Br3) beds, Pripyat Depression (Kedo, 1966; Byvsheva 1967, 1974).
10. Tula beds, Pripyat Depression (Kedo, 1966; Byvsheva, 1967, 1974).

Spitsbergen (Playford, 1962, 1963; Dibner, 1966). The *Aurita* assemblage described by Playford (1962, 1963) was believed to be of Viséan to possibly early Namurian age; this age determination was based on comparisons made with the then known assemblages from the U.S.S.R., United States, Canada, and Europe. Since that time, considerable detailed palynological data have become available from different parts of the world. Precise correlation is still difficult, although in this paper a late Viséan V_3 age is suggested (Fig. 6.7). Species from the Emma Fiord Formation also found in Spitsbergen, Western Europe and the Donetz Basin of the U.S.S.R. are shown in Table 6.3.

On Bjørnøya (Bear Island), published data are available from the upper part of the Nordkapp Formation (Playford, 1963; Kaiser, 1970, 1971). The assemblage listed by Playford (1963) includes *Cingulizonates bialatus*, *Lycospora pusilla*, *Spelaeotriletes balteatus*, and *Diatomozonotriletes saetosus*. That recorded by Kaiser (1970) (and dated as Viséan V_3) has many species in common with the Grinnell material, including *Murospora aurita*, *Waltzispora planiangulata*, *Verrucosisporites papulosus*, *Convolutispora vermiformis*, *Microreticulatisporites hortonensis*, *Reticulatisporites peltatus* = *Cordylosporites papillatus*, *Murospora intorta*, *Murospora sublobata*, *Densosporites anulatus*, *Lycospora pusilla*, and *Diatomozonotriletes saetosus*. It seems probable that this material may be of similar age to that of Kleybolte and Svartevaeg and was tentatively assigned to the NM Zone of Western Europe by J.O. Vigran (pers. comm., 1987).

Correlation with the zonal scheme of Scotland and northern England (Neves et al., 1973) and Western Europe (Clayton et al., 1977), and the biostratigraphic conclusions reached, should be treated with caution because of the fact that Western Europe was in a different floral province in Viséan times, i.e. the *Grandispora* suite or microflora (Sullivan, 1965; Clayton, 1985). Comparisons made suggest a tentative correlation of most of the Emma Fiord Grinnell material with the *Raistrickia nigra - Triquitrites marginatus* (NM) Zone of Asbian or middle late Viséan (middle V_3) age. The NM Zone has been subdivided into two subzones (Clayton, 1985); the upper *Murospora margodentata - Rotaspora ergonulii* (ME) Zone is based on the first appearance of *Murospora margodentata* Beju, and the lower zone, *Tripartites distinctus - Murospora parthenopia* (DP), on the appearance of *Raistrickia nigra* Love and *Triquitrites marginatus* Hoffmeister, Staplin, and Malloy. None of these species occurs in the Emma Fiord material. The following species are found in both the Grinnell and Western European localities: *Auroraspora solisorta*, *Cingulizonates bialatus*, *Colatisporites decorus*, *Cribrosporites cribellatus*, *Densosporites anulatus*, *Diatomozonotriletes saetosus*, *Knoxisporites literatus*, *K. stephanephorus*, *K. triradiatus*, *Lycospora pusilla*, *Perotrilites tessellatus*, *Rotaspora fracta*, *Tricidarisporites arcuatus*, *T. magnificus*, and *Waltzispora planiangulata*. One significant difference is the common occurrence of *Murospora aurita* in the Emma Fiord material, and its rarity in Western Europe.

The presence of rare specimens of *Rotaspora fracta* in the upper part of Grinnell locality 1, suggests a correlation with the *Tripartites vetustus - Rotaspora fracta* (VF) Zone of Brigantian (late V_3 age). However, many of the other species diagnostic of the VF Zone are lacking, as are also many species of the *Diatomozonotriletes saetosus* Assemblage II of Smith and Butterworth (1967), which, according to Clayton et al. (1977), is approximately correlative with the VF Zone.

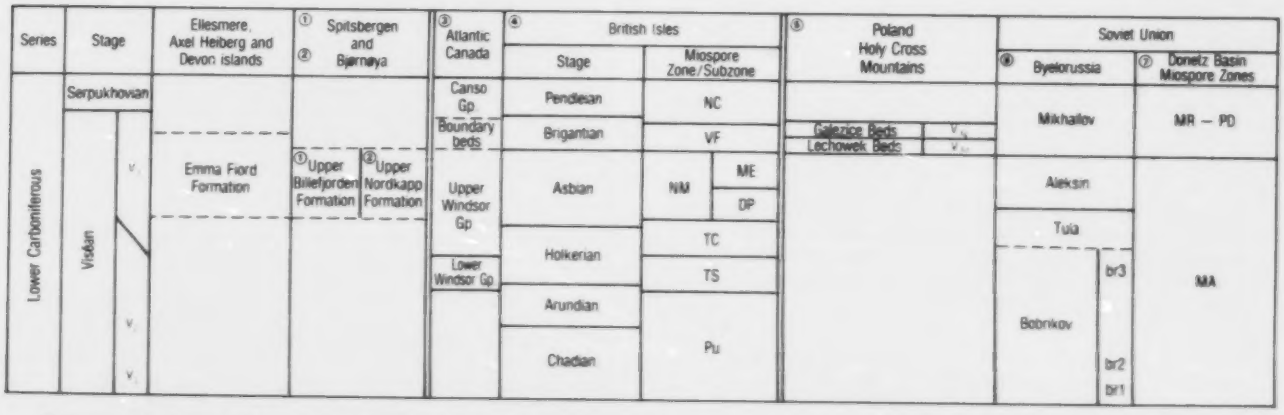

Figure 6.7. *Correlation of the Emma Fiord Formation assemblages with those from Spitsbergen, Bjørnøya, Atlantic Canada, British Isles, Poland and Soviet Union. The vertical distribution has been plotted in alphabetical order rather than by first appearance because the relative stratigraphic position of the three sections is uncertain. Data sources include 1. Spitsbergen (Playford 1962, 1963), 2. Bjørnøya (Playford, 1962, 1963; Kaiser 1970, 1971; J.O. Vigran, pers. comm., 1987), 3. Atlantic Canada (Utting, 1987a), 4. British Isles (Clayton et al., 1977, Clayton, 1985), 5. Poland (Jachowicz, 1970), 6. Byelorussia, Soviet Union (Kedo, 1966; Byvsheva, 1967, 1974), 7. Donetz Basin, Soviet Union (Owens et al. 1978).*

*Miospore zones and subzones of the British Isles are abbreviated as follows: Pu, **Lycospora pusilla** Zone; TS, **Knoxisporites triradiatus - Knoxisporites stephanephorus** Zone; TC, **Perotrilites tessellatus - Schulzospora campyloptera** Zone; NM, **Raistrickia nigra -Triquitrites marginatus** Zone; DP, **Triquitrites distinctus - Murospora parthenopia** Subzone of NM Zone; ME, **Murospora margodentata - Rotaspora ergonulii** Subzone of NM Zone; VF, **Tripartites vetustus - Rotaspora fracta** Zone; NC, **Bellispores nitidus -Reticulatisporites carnosus** Zone.*

*Miospore zones of Donetz Basin, Soviet Union are abbreviated as follows: Ma, **Murospora aurita** Zone, MR-PD, **Microsporites radiatus - Potoniespores delicatus** Zone.*

It is difficult to make a precise correlation between the Kleybolte and Svartevaeg material and that from Western Europe, owing to the poor preservation and lack of diversity in the former. However, the presence of *Perotrilites tessellatus* and *Spelaeotriletes arenaceus*, rare specimens of *Diatomozonotriletes saetosus* and *Triadnrisporites magnificus*, and the abundance of *Densosporites*, indicate a correlation with the *Raistrickia nigra – Triquitrites marginatus* (NM) Zone, or the *Tripartites vetustus - Rotaspora fracta* (VF) Zone. Rare specimens of *Rotaspora fracta* occur in one sample (GSC loc. C-107577) from Kleybolte Peninsula.

In Poland, assemblages from the Lechowek (V111d) and Galezice (V111g) formations of the Holy Cross Mountains are approximately coeval with or slightly younger than those of the Emma Fiord Formation; they include species such as *Savitrisporites nux*, *Waltzispora planiangulata*, *Diatomozonotriletes saetosus*, *Rotaspora knoxi*, and *Schulzospora rara*. Beds of lower to middle V_3 age are apparently lacking.

Comparison of the Emma Fiord assemblages with those of the Soviet Union suggests similarities with those described by Kedo (1966) and Byvsheva (1967, 1974) from the Lower Carboniferous uppermost Bobrikov (br3) and the Tula beds of the Pripyat Depression of Byelorussia. The following species are common to both areas: *Cingulizonates bialatus*, *Colatisporites decorus*, *Diatomozonotriletes saetosus*, *Labiadensites fimbriatus*, *Lycospora pusilla*, *Murospora aurita*, and *Murospora intorta*. The material described by Kedo (1966) and Byvsheva (1967, 1974) from the Tula beds of the Pripyat Depression is similar to that from Kleybolte and Svartevaeg in that there is an abundance of *Cingulizonates bialatus* and *Lycospora pusilla*.

There are many similarities between the Emma Fiord material and the *Murospora aurita* (MA) Zone of the Donetz Basin, which according to Owens et al. (1978), is equivalent to the middle and upper parts of the *Lycospora pusilla* (Pu) Zone (sensu Clayton et al., 1977), the *Perotrilites tessellatus - Schulzospora campyloptera* (TC) Zone and the *Raistrickia nigra - Triquitrites marginatus* (NM) Zone of Western Europe. Common to the Grinnell Emma Fiord and Donetz Viséan material are *Auroraspora macra*, *Grandispora uncata*, *Tripartites incisotrilobus*, *Murospora aurita*, *Knoxisporites literatus*, *Lycospora pusilla*, *Perotrilites tessellatus*, and *Rotaspora fracta*. A correlation with the uppermost part of the *Murospora aurita* (MA) Zone is proposed on the basis of the appearance of *Rotaspora fracta*.

Conclusions

1. The Emma Fiord Formation miospore assemblages from Grinnell Peninsula are in some intervals very diverse and well preserved. The thermal maturity is low (TAI 2-). Those from Svartevaeg Cliffs, Axel Heiberg Island, and Kleybolte Peninsula, Ellesmere Island, are less diverse and thermally altered (TAI 4-to 5).

2. A tentative correlation of the Grinnell material and the Kleybolte and Svartevaeg material within the range of the *Raistrickia nigra - Triquitrites marginatus* (NM) Zone and with the *Tripartites vetustus - Rotaspora fracta* (VF) Zone of Western Europe is suggested, thus indicating a middle to late Viséan V_3 age.

3. The Emma Fiord assemblages differ significantly from those of approximately similar age from Atlantic Canada (Upper Windsor Group and Windsor/Canso boundary beds, suggesting that these parts of Canada were in different floral provinces during the Viséan.

SYSTEMATIC DESCRIPTIONS

Anteturma SPORITES H. Potonié, 1893

Turma TRILETES Reinsch, 1881 emend. Potonié and Kremp, 1954

Suprasubturma ACAMERATITRILETES Neves and Owens, 1966

Subturma ZONOTRILETES Waltz, 1935

Infraturma CINGULICAVATI Smith and Butterworth, 1967

Genus *Cristatisporites* (Potonié and Kremp) Butterworth, Jansonius, Smith, and Staplin, 1964

Type species. *Cristatisporites indignabundus* (Loose) Potonié and Kremp, 1954.

Cristatisporites apisaculeus sp. nov. Utting

Plate 6.2, figures 2-8

Holotype. GSC 92863, slide 3B, 15.4 x 111.2, Pl. 6.2, figs. 2, 3, GSC locality C-32929.

Other figured specimens. GSC 92864, slide 3A, 26.8 x 97.8, Pl. 6.2, fig. 4, GSC loc. C-32932. GSC 92865, slide 3A, 31.4 x 102.5, Pl. 6.2, fig. 5, GSC loc. C-32962. GSC 92866, slide 3A, 29.3 x 95.2, Pl. 6.2, fig. 6, GSC loc. 32976. GSC 92867, slide 3A, 19.2 x 99.1, Pl. 6.2, fig. 7, GSC loc. 32905. GSC 92868, slide 3A, 11.2 x 107.2, Pl. 6.2, fig. 8, GSC loc. C-32905.

Occurrence. Common in some samples from the Grinnell sections of the Emma Fiord Formation, Devon Island.

Diagnosis. Trilete miospores, amb rounded triangular to subcircular. Laesurae straight extend approximately three quarters of spore radius to inner margin of cingulum; associated folds, sinuous in outline, up to 2 µm high, border laesurae. Thin mesosporoid (0.3-0.5 µm) commonly visible subparallel to inner margin of cingulum, often with secondary folds. Cingulum up to 3 µm wide. Exine punctate. Distal and equatorial ornament of scattered biform processes consisting of a basal rounded conus or pilum, up to 3 µm high and 6 µm in basal diameter with, at tip, aciculate spinae having a basal diameter of 0.3 to 1.0 µm and up to 4.0 µm high. On some specimens tapered coni and verrucae occur. Elements 2 to 10 µm apart, sometimes with basal elements coalescing.

Dimensions. Equatorial diameter excluding sculptured projections: 39-60 µm, mean 43 µm (20 specimens).

Remarks. Small (less than 0.3 µm) shallow pits and grooves are distributed radially around outer margin of spore body on some specimens, and may represent corrosion of the exine.

The most appropriate genus for this species is *Cristatisporites*, which is zonate and characterized by distal mammoids or verrucae that bear setose tips.

On some specimens, the bases of some of the elements coalesce, a typical feature of *Cristatisporites* (Potonié and Kremp, 1954), but in most specimens they are discrete. Unlike the emended diagnosis of Butterworth et al. (in Staplin and Jansonius, 1964) no setose ring at the inner margin of the cingulum on the proximal surface, was seen. The possibility of including this species in *Densosporites* Berry, 1937, was also considered, but rejected because this genus does not normally bear prominent ornament on the central distal area, although it may occur on the cingulum (Butterworth et al., 1964 in Staplin and Jansonius, 1964).

Cristatisporites sp. cf. *C. connexus* Potonié and Kremp, in Staplin and Jansonius, 1964, possesses a denser ornament of verrucae with setose tips, than *C. apisaculeus* and the zona is wider. *Spinozonotriletes*? *exiguus* Staplin, 1960 is similar but has a denser ornament and is smaller (27-36 μm). *C. apisaculeus* resembles *Densosporites aculeatus* Playford (1963), but differs in bearing biform processes rather than conspicuously tapering single spinae, and in having a narrower cingulum.

Derivation of name. Latin, *apis*, honey bee; Latin, *aculeus*, sting (the aciculate processes on the biform elements resemble the sting of a queen honey bee).

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PLATES 6.1 TO 6.6

All figures approximately x500. All specimens are housed in the National Type Collection of the Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada.

In the explanation of figures, the species name is followed by the GSC type number, slide number, stage co-ordinates, and the GSC locality number.

PLATE 6.1

(Emma Fiord Formation, Grinnell Peninsula, Devon Island)

Figure 1. *Acanthotriletes* sp.

GSC 92840, slide 4A, 19.5 x 96.0, GSC loc. C-32931.

Figure 2. *Acanthotriletes* sp. cf. *A. mirus*

GSC 92841, slide 3B, 9.1 x 106.6, GSC loc. C-32932.

Figure 3. *Acanthotriletes socraticus*

GSC 92842, slide 3A, 10.0 x 98.0, GSC loc. C-32905.

Figures 4, 5. *Apiculatisporis baccatus*

4. GSC 92843, slide 3A, 34.2 x 107.1 (Tetrad) GSC loc. C-32910.
5. GSC 92844, slide 3A, 40.2 x 101.2 (Tetrad) GSC loc. C-32910.

Figure 6. *Auroraspora macra*

GSC 92845, slide 3A, 17.6 x 110.1, GSC loc. C-32932.

Figure 7. *Auroraspora solisorta*

GSC 92846, slide 3A, 8.2 x 98.1, GSC loc. C-32910.

Figure 8. *Calamospora breviradiata*

GSC 92847, slide 3A, 8.4 x 94.6, GSC loc. C-32910.

Figure 9. *Calamospora microrugosa*

GSC 92848, slide 4A, 35.5 x 108.5, GSC loc. C-32901.

Figure 10. *Camptozonotriletes velatus*

GSC 92849, slide 3B, 17.4 x 107.6, GSC loc. C-32929.

Figure 11. *Chomotriletes multivittatus*

GSC 92850, slide 3A, 6.4 x 98.4, GSC loc. C-32978.

Figures 12, 15-16. *Colatisporites decorus*

12. GSC 92852, slide 4A, 36.8 x 105.0, GSC loc. C-32907.
15. GSC 92853, slide 3A, 22.2 x 103.0, GSC loc. C-32910.
16. GSC 92854, slide 3A, 11.4 x 96.0, GSC loc. C-32910.

Figure 13. *Cingulizonates bialatus*

GSC 92851, slide 3A, 32.0 x 98.6, GSC loc. C-32910.

Figure 14. *Convolutispora* sp.

GSC 92856, slide 3A, 25.3 x 106.5, GSC loc. C-32905.

Figure 17. *Convolutispora florida*

GSC 92855, slide 3A, 22.5 x 103.5, GSC loc. C-32910.

Figure 18. *Convolutispora tuberculata*

GSC 92858, slide 3A, 18.2 x 109.7, GSC loc. C-32979.

Figure 19. *Convolutispora tessellata*

GSC 92857, slide 4A, 28.9 x 105.1, GSC loc. C-32892.

Figure 20. *Convolutispora usitata*

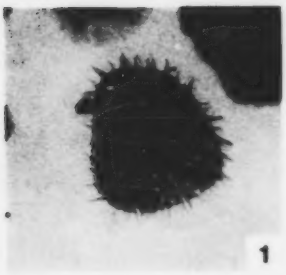
GSC 92859, slide 4A, 25.5 x 99.2, GSC loc. C-32901.

Figure 21. *Convolutispora venusta*

GSC 92860, slide 4A, 29.4 x 106.5, GSC loc. C-32910.

Figure 22. *Convolutispora vermiformis*

GSC 92861, slide 3A, 14.2 x 108.2, GSC loc. C-32927.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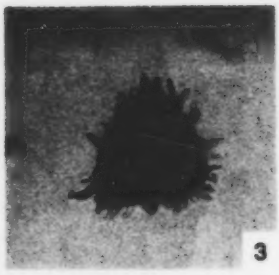
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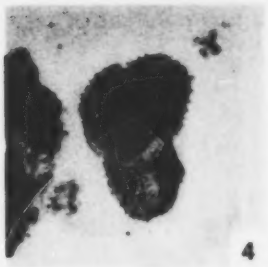
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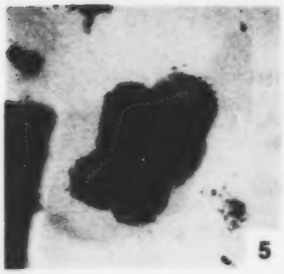
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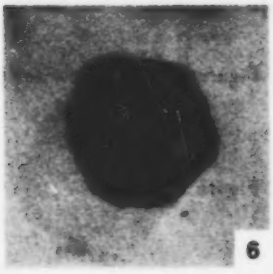
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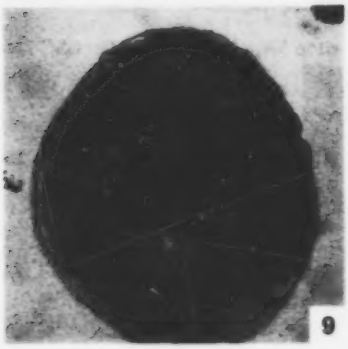
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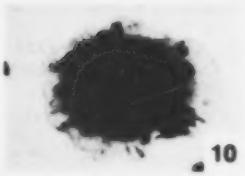
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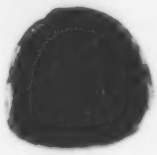
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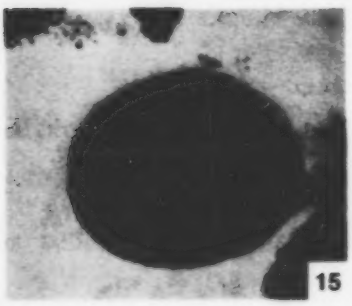
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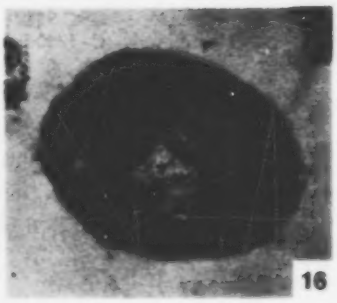
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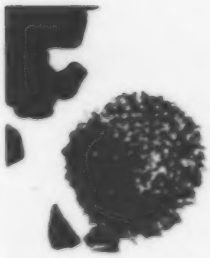
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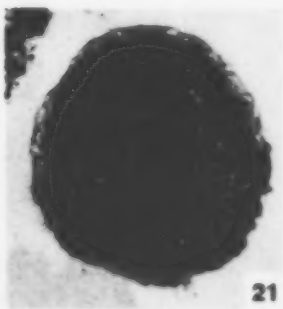
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PLATE 6.2

(Emma Fiord Formation, Grinnell Peninsula, Devon Island)

Figure 1. *Cribrosporites cribellatus*

GSC 92862, slide 3B, 23.2 x 101.5, GSC loc. C-32932.

Figures 2-8. *Cristatisporites apisaculeus* sp. nov.

2. Holotype GSC 92863, slide 3B, 15.4 x 111.2, GSC loc. C-32929.
3. Detail of ornament (x 1250) of specimen illustrated in figure 2
4. GSC 92864, slide 3A, 26.8 x 97.8, GSC loc. C-32932.
5. GSC 92865, slide 3A, 31.4 x 102.5, GSC loc. C-32962.
6. GSC 92866, slide 3A, 29.3 x 95.2, GSC loc. C-32976.
7. GSC 92867, slide 3A, 19.2 x 99.1, GSC loc. C-32905.
8. GSC 92868, slide 3A, 11.2 x 107.2, GSC loc. C-32905.

Figure 9. *Cyclogranisporites lasius*

GSC 92869, slide 3B, 17.5 x 96.8, GSC loc. C-32931.

Figure 10. *Cyclogranisporites* sp. cf. *C. palaeophytus*

GSC 92870, slide 3B, 40.7 x 94.6, GSC loc. C-32929.

Figure 11. *Densosporites anulatus*

GSC 92871, slide 3A, 31.7 x 100.0, GSC loc. C-32905.

Figure 12. *Densosporites rarispinosus*

GSC 92872, slide 3B, 9.7 x 107.4, GSC loc. C-32929.

Figure 13. *Densosporites subcrenatus*

GSC 92873, slide 3A, 6.2 x 106.2, GSC loc. C-32932.

Figure 14. *Densosporites variabilis*

GSC 92874, slide 4B, 20.0 x 104.2, GSC loc. C-32901.

Figure 15. *Diatomozonotriletes hughesii*

GSC 92875, slide 3A, 25.0 x 105.6, GSC loc. C-32946.

Figure 16. *Diatomozonotriletes rarus*

GSC 92876, slide 3A, 36.4 x 93.3, GSC loc. C-32912.

Figure 17. *Diatomozonotriletes saetosus*

GSC 92877, slide 3A, 15.5 x 103.7, GSC loc. C-32907.

Figure 18. *Cordylosporites* sp.

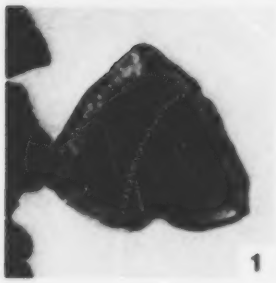
GSC 92878, slide 3A, 24.2 x 105.4, GSC loc. C-32905.

Figure 19. *Discernisporites* sp.

GSC 92879, slide 3B, 40.2 x 105.7, GSC loc. C-32932.

Figure 20. *Grandispora* sp.

GSC 92880, slide 3A, 10.0 x 99.0, GSC loc. C-32927.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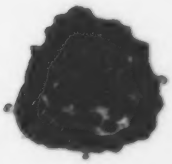
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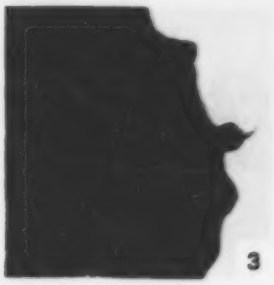
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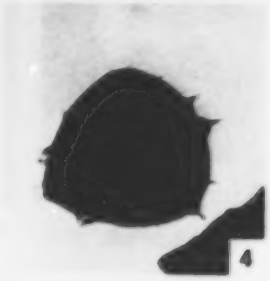
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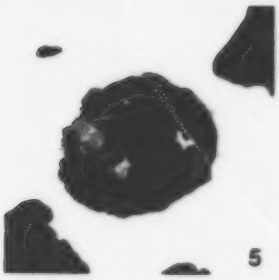
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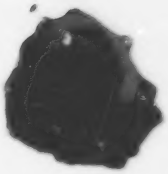
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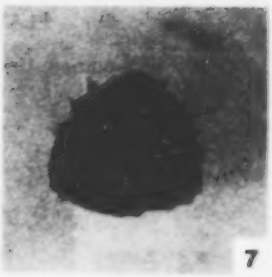
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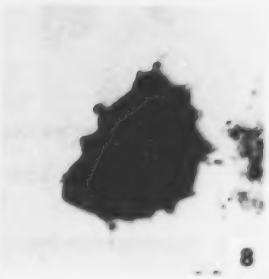
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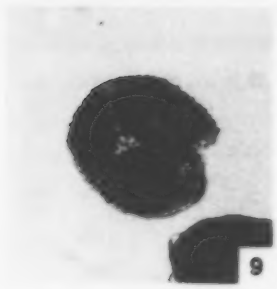
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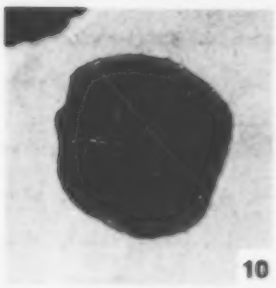
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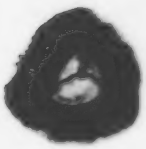
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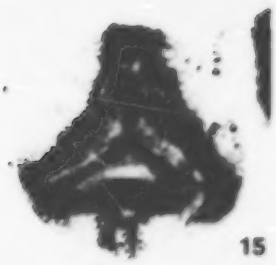
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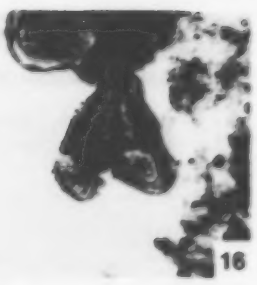
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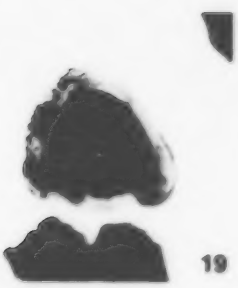
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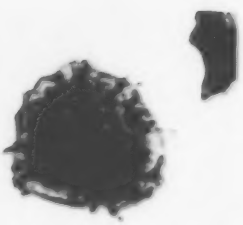
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PLATE 6.3

(Emma Fiord Formation, Grinnell Peninsula, Devon Island)

Figure 1. *Discernisporites micromanifestus*

GSC 92881, slide 4A, 25.8 x 102.2, GSC loc. C-32899.

Figure 2. *Foveosporites insculptus*

GSC 92882, slide 4A, 17.1 x 108.8, GSC loc. C-32927.

Figure 3. *Granulatisporites granulatus*

GSC 92884, slide 3A, 18.6 x 96.2, GSC loc. C-32976.

Figure 4. *Knoxisporites literatus*

GSC 92885, slide 3A, 30.6 x 102.0, GSC loc. C-32916.

Figures 5, 6. *Kraeuselisporites* sp.

5. GSC 92892, slide 4A, 14.8 x 100.6, GSC loc. C-32909, proximal surface in focus.
6. Distal surface in focus of specimen illustrated in figure 5.

Figure 7. *Grandispora uncata*

GSC 92883, slide 4A, 20.7 x 98.7, GSC loc. C-32908.

Figure 8. *Latosporites* sp.

GSC 92895, slide 4A, 19.1 x 102.2, GSC loc. C-32892.

Figure 9. *Knoxisporites rotatus*

GSC 92886, slide 4A, 30.6 x 94.0, GSC loc. C-32932.

Figure 10. *Knoxisporites stephanephorus*

GSC 92887, slide 3B, 39.9 x 107.1, GSC loc. C-32932.

Figures 11-14. *Knoxisporites triradiatus*

11. GSC 92888, slide 3A, 20.2 x 108.2, GSC loc. C-32910.
12. GSC 92889, slide 3B, 22.6 x 97.0, GSC loc. C-32932.
13. GSC 92890, slide 3A, 19.5 x 109.0, GSC loc. C-32905.
14. GSC 92891, slide 3A, 7.6 x 95.9, GSC loc. C-32905.

Figures 15, 16. *Labiadensites fimbriatus*

15. GSC 92894, slide 4A, 21.4 x 104.5, GSC loc. C-32907.
16. GSC 92893, slide 4A, 27.5 x 98.8, GSC loc. C-32901.

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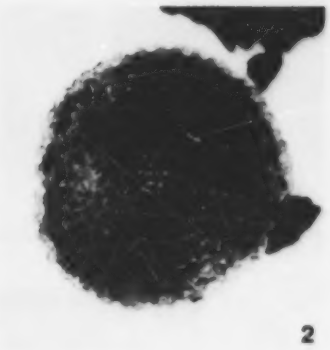
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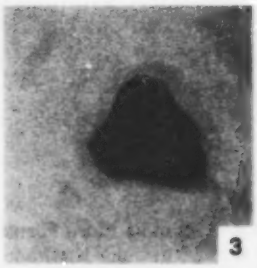
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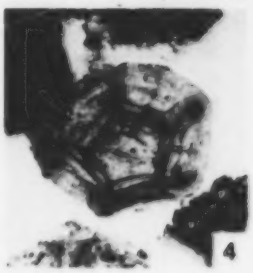
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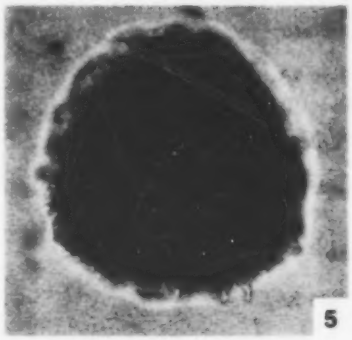
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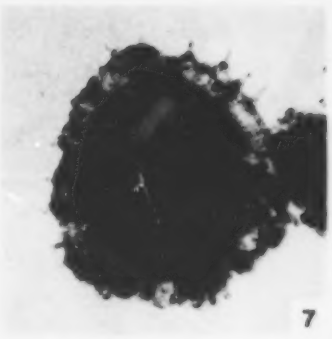
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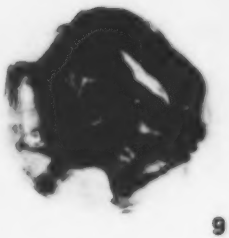
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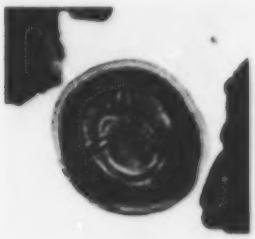
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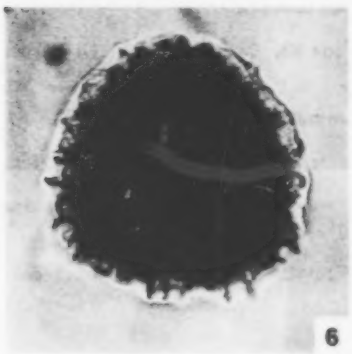
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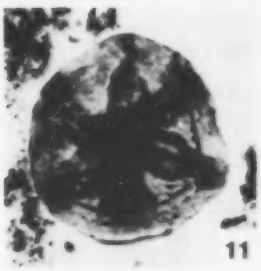
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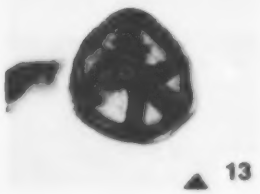
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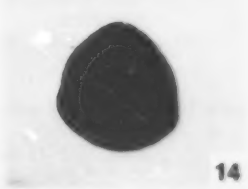
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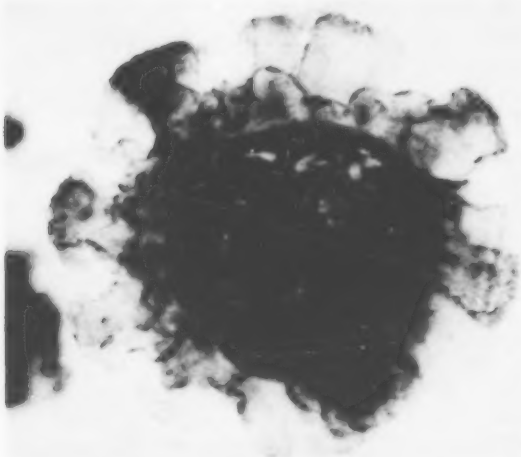
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PLATE 6.4

(Emma Fiord Formation, Grinnell Peninsula, Devon Island)

Figure 1. *Leiotriletes ornatus*

GSC 92896, slide 3A, 35.1 x 104.0, GSC loc. C-32909.

Figure 2. *Lophozonotriletes* sp.

GSC 92897, slide 3A, 27.7 x 97.7, GSC loc. C-32915.

Figure 3. *Lycospora pusilla*

GSC 92898, slide 3A, 8.5 x 99.0, GSC loc. C-32960.

Figure 4. *Microreticulatisporites concavus*

GSC 92899, slide 3A, 15.0 x 98.3, GSC loc. C-148189.

Figure 5. *Perotrilites perinatus*

GSC 92906, slide 3A, 22.7 x 107.3, GSC loc. C-32910.

Figures 6, 7. *Murospora aurita*

6. GSC 92900, slide 3A, 21.6 x 102.4, GSC loc. C-32910.
7. GSC 92901, slide 4A, 40.3 x 101.1, GSC loc. C-32908.

Figure 8. *Murospora conduplicata*

GSC 92902, slide 4A, 30.1 x 102.0, GSC loc. C-32901.

Figure 9. *Murospora sublobata*

GSC 92903, slide 3A, 21.8 x 93.7, GSC loc. C-32912.

Figures 10, 11. *Murospora tripulvinata*

10. GSC 92904, slide 4A, 4.5 x 110.4, GSC loc. C-32910.
11. GSC 92905, slide 4A, 12.3 x 107.3, GSC loc. C-32901.

Figure 12. *Umbonatisporites* sp. cf. *U. distinctus*

GSC 92910, slide 4A, 29.7 x 97.8, GSC loc. C-32929.

Figure 13. *Perotrilites tessellatus*

GSC 92907, slide 4A, 36.4 x 100.4, GSC loc. C-32901.

Figure 14. *Punctatisporites glaber*

GSC 92908, slide 3A, 22.3 x 96.1, GSC loc. C-32964.

Figure 15. *Rotaspora fracta*

GSC 92915, slide 3A, 14.5 x 96.2, GSC loc. C-32910.

Figure 16. *Reticulatisporites cancellatus*

GSC 92912, slide 4B, 21.7 x 105.7, GSC loc. C-32902.

Figure 17. *Reticulatisportes rudis*

GSC 92914, slide 3A, 25.5 x 95.2, GSC loc. C-32907.

Figure 18. *Raistrickia* sp. cf. *R. ponderosa*

GSC 92911, slide 4B, 25.4 x 101.0, GSC loc. C-32902.

Figure 19. *Raistrickia golatensis*

GSC 92909, slide 3A, 20.4 x 108.7, GSC loc. C-32905.

Figure 20. *Cordylosporites papillatus*

GSC 92913, slide 4B, 27.0 x 107.7, GSC loc. C-32907.

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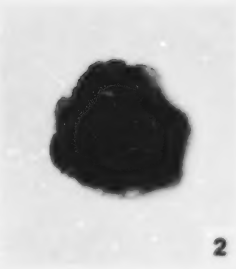
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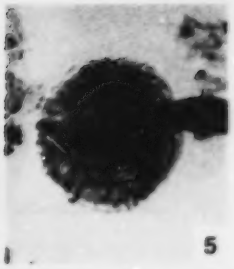
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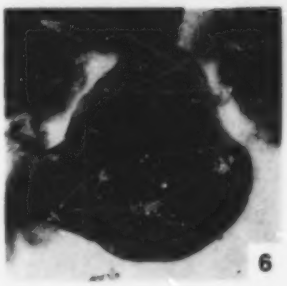
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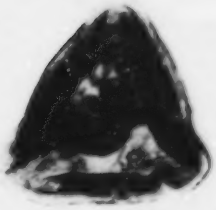
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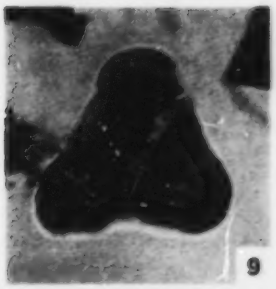
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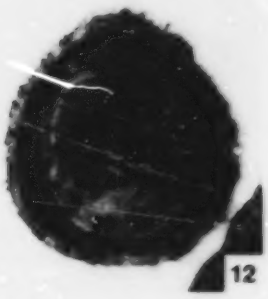
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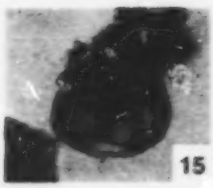
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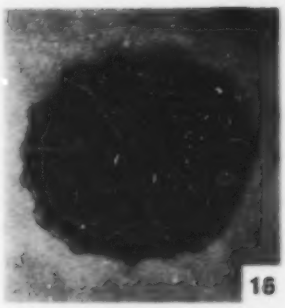
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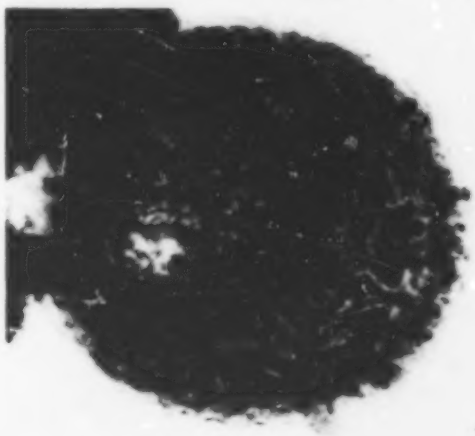
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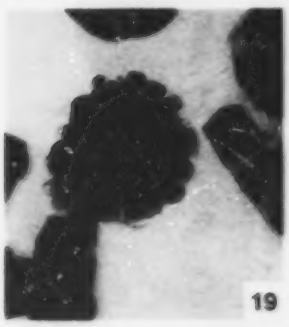
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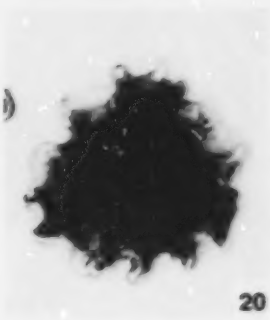
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PLATE 6.5

(Emma Fiord Formation, Grinnell Peninsula, Devon Island)

Figure 1. *Rugospora corporata* var. *verrucosa*

GSC 92916, slide 4B, 29.1 x 103.4, GSC loc. C-32901.

Figure 2. *Secarisporites remotus*

GSC 92918, slide 4A, 23.1 x 110.0, GSC loc. C-32892.

Figure 3. *Spelneotriletes balteatus*

GSC 92921, slide 3A, 26.4 x 105.5, GSC loc. C-32932.

Figure 4. *Rugospora polyptycha*

GSC 92917, slide 3A, 12.2 x 107.0, GSC loc. C-32905.

Figures 5, 6. *Spelaeotriletes arenaceus*

5. GSC 92919, slide 3A, 27.4 x 103.7, GSC loc. C-32905.
6. GSC 92920, slide 3A, 32.5 x 105.2, GSC loc. C-32905.

Figure 7. *Spelaeotriletes tuberosus*

GSC 92922, slide 3A, 6.0 x 107.2, GSC loc. C-32905.

Figure 8. *Stenozonotriletes clarus*

GSC 92923, slide 1A, 48.2 x 106.1, GSC loc. C-32909.

Figure 9. *Tripartites pressuens*

GSC 92926, slide 4A, 34.5 x 98.2, GSC loc. C-32909.

Figure 10. *Tripartites incisotrilobus*

GSC 92927, slide 3A, 16.2 x 106.5, GSC loc. C-32915.

Figures 11, 12. *Vallatisporites* sp.

11. GSC 92928, slide 4A, 32.4 x 96.7, GSC loc. C-32901.
12. GSC 92929, slide 4A, 29.5 x 98.7, GSC loc. C-32901.

Figures 13, 14. *Tricidarisporites arcuatus*

13. GSC 92924, slide 3B, 25.3 x 96.7, GSC loc. C-32905.
14. GSC 92925, slide 3B, 19.1 x 98.2, GSC loc. C-32905.

Figure 15. *Verrucosisporites papulosus*

GSC 92931, slide 3A, 41.3 x 104.5, GSC loc. C-32978.

Figure 16. *Waltzispora planiangulata*

GSC 92932, slide 3A, 19.4 x 108.8, GSC loc. C-32905.

Figure 17. *Waltzispora sagittata*

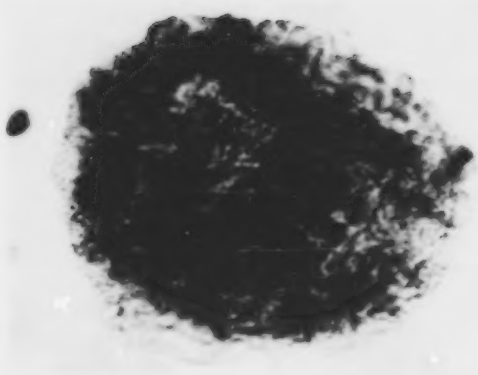
GSC 92933, slide 3A, 2.9 x 103.8, GSC loc. C-32912.

Figure 18. *Waltzispora* sp.

GSC 92934, slide 3A, 27.2 x 97.2, GSC loc. C-32907.

Figure 19. *Verrucosisporites* sp. cf. *V. eximius*

GSC 92930, slide 4A, 35.0 x 104.2, GSC loc. C-32892.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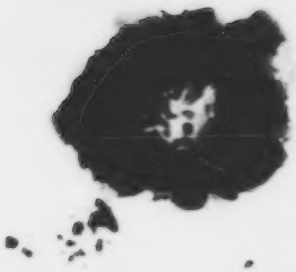
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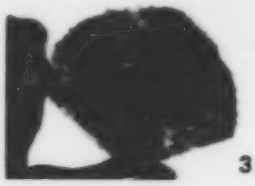
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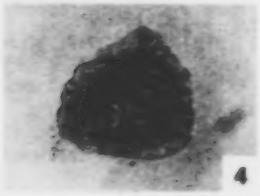
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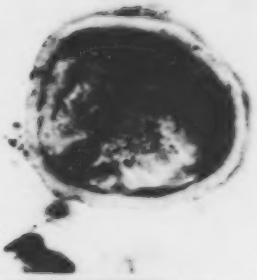
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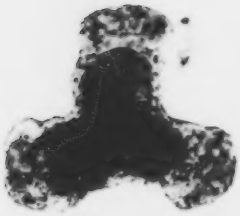
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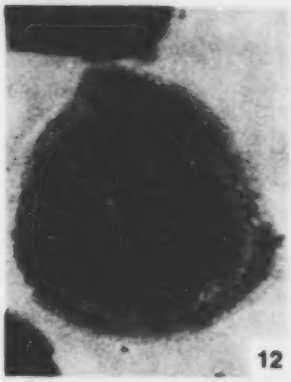
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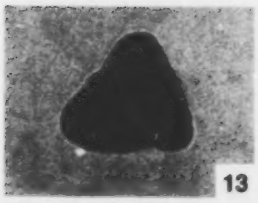
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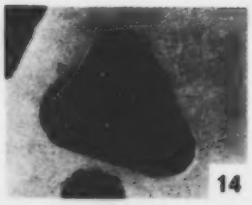
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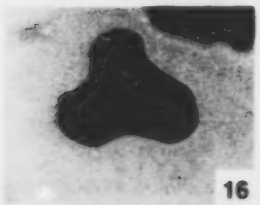
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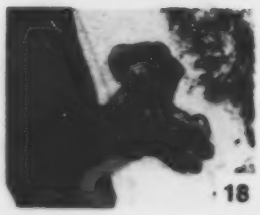
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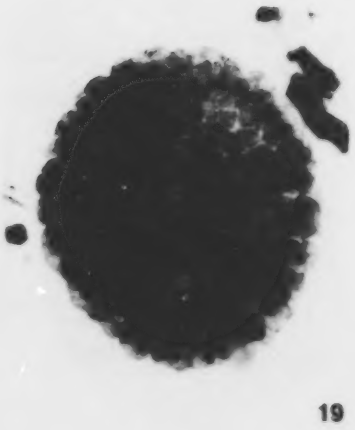
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PLATE 6.6

(Emma Fiord Formation, Kleybolte Peninsula, Ellesmere Island and Svartevaeg Cliffs, Axel Heiberg Island)

Figure 1. *Cribrosporites cribellatus*

1. GSC 92935, slide 4A, 7.0 x 105.2, GSC loc. C-134495.

Figures 2-4. *Cingulizonates bialatus*

2. GSC 92936, slide 3A, 24.2 x 108.2, GSC loc. C-134495.
3. GSC 92937, slide 3A, 15.7 x 110.8, GSC loc. C-134495.
4. GSC 92938, slide 3A, 28.8 x 109.0, GSC loc. C-134495.

Figure 5. *Densosporites dentatus*

GSC 92939, slide 3A, 5.6 x 108.4, GSC loc. C-134495.

Figure 6. *Densosporites rarispinosus*

GSC 92940, slide 3A, 40.4 x 109.2, GSC loc. C-134495.

Figure 7. *Densosporites subcrenatus*

GSC 92941, slide 3A, 38.0 x 105.6, GSC loc. C-134495.

Figure 8. *Densosporites spitsbergensis*

GSC 92942, slide 3A, 17.4 x 107.3, GSC loc. C-134495.

Figure 9. *Diatomozonotriletes hughesii*

GSC 92943, slide 3A, 21.3 x 103.7, GSC loc. C-107577.

Figure 10. *Diatomozonotriletes rarus*

GSC 92944, slide 3A, 13.6 x 96.7, GSC loc. C-107577.

Figure 11. *Diatomozonotriletes saetosus*

GSC 92945, slide 3A, 34.8 x 98.7, GSC loc. C-107577.

Figure 12. *Foveosporites* sp.

GSC 92946, slide 4A, 25.3 x 104.1, GSC loc. C-134495.

Figure 13. *Granulatisporites granulatus*

GSC 92947, slide 3A, 10.7 x 102.5, GSC loc. C-107577.

Figure 14. *Leiotriletes inermis*

GSC 92948, slide 3A, 30.8 x 96.5, GSC loc. C-134495.

Figure 15. *Leiotriletes ornatus*

GSC 92949, slide 3A, 20.0 x 103.5, GSC loc. C-134495.

Figure 16. *Lycospora noctuina*

GSC 92950, slide 3A, 14.7 x 109.0, GSC loc. C-134495.

Figure 17. *Lycospora pusilla*

GSC 92951, slide 3A, 30.0 x 98.1, GSC loc. C-134495.

Figure 18. *Knoxisporites stephanephorus*

GSC 92952, slide 3A, 13.5 x 108.9, GSC loc. C-134495.

Figure 19. *Rotaspora fracta*

GSC 92960, slide 3A, 27.9 x 100.0, GSC loc. C-107577.

Figure 20. *Waltzispora planiangulata*

GSC 92963, slide 4A, 38.6 x 99.1, GSC loc. C-134495.

Figure 21. Probable aberrant form of *Murospora aurita* (cf. Playford, 1962, Pl. 87, fig. 9)

GSC 92953, slide 3A, 26.4 x 103.2, GSC loc. C-134495.

Figure 22. *Murospora aurita*

GSC 92954, slide 4A, 37.6 x 94.3, GSC loc. C-134495.

Figure 23. *Murospora aurita*

GSC 92955, slide 4A, 6.4 x 105.5, GSC loc. C-134495.

Figure 24. *Murospora sublobata*

GSC 92956, slide 3A, 18.2 x 96.8, GSC loc. C-134495.

Figure 25. *Tricidarisporites magnificus*

GSC 92962, slide 3A, 19.0 x 94.2, GSC loc. C-134495.

Figure 26. *Perotrilites tessellatus*

GSC 92957, slide 3A, 36.2 x 97.0, GSC loc. C-107573.

Figure 27. *Reticulatisporites cancellatus*

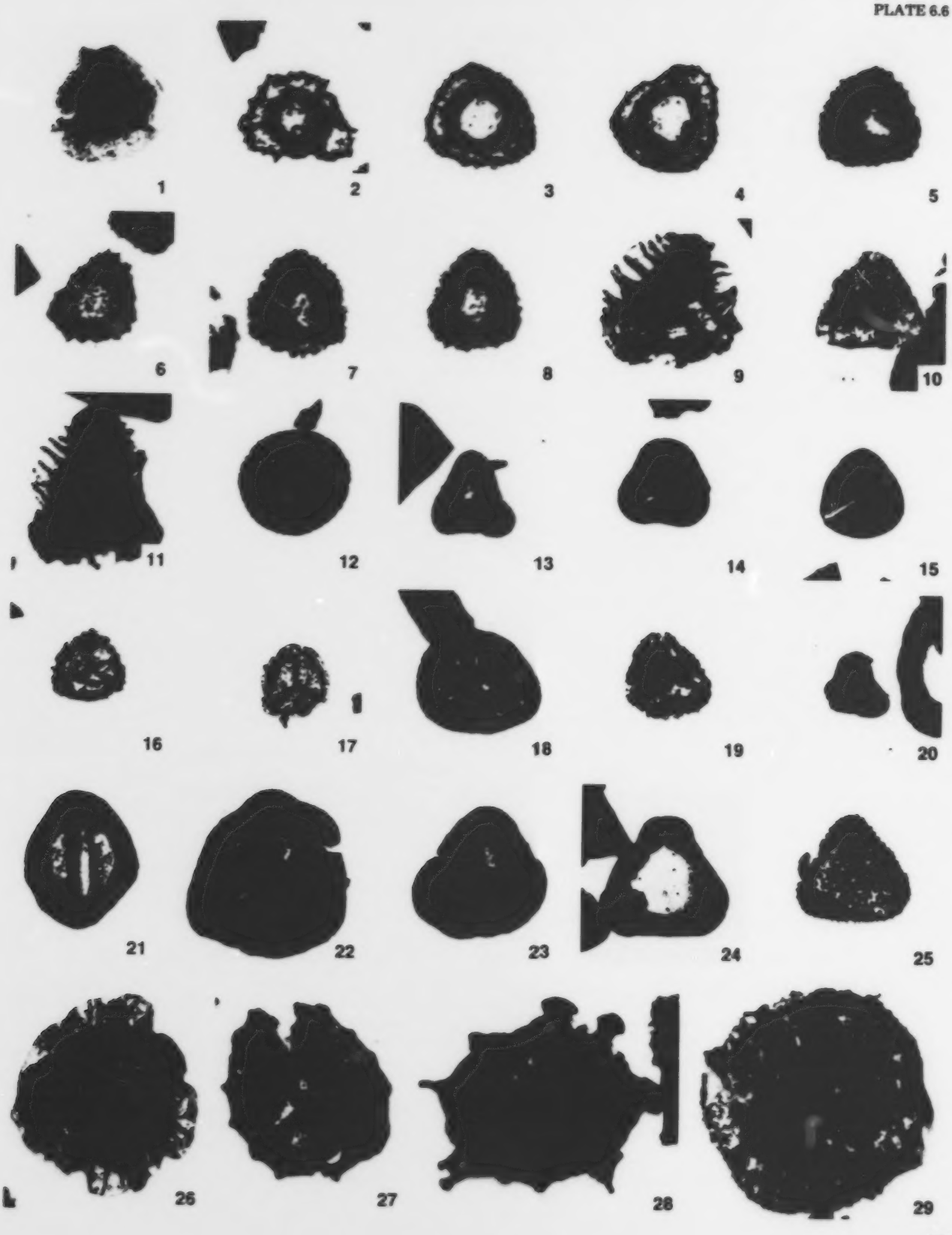
GSC 92958, slide 4A, 27.6 x 94.6, GSC loc. C-134495.

Figure 28. *Cordylosporites papillatus*

GSC 92959, slide 4A, 26.5 x 95.0, GSC loc. C-134495.

Figure 29. *Spelaeotriletes arenaceus*

GSC 92961, slide 4A, 35.2 x 96.4, GSC loc. C-134497.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JURASSIC (OXFORDIAN) AMMONITES FROM THE FERNIE FORMATION OF WESTERN CANADA: A GIANT PELTOCERATINID, AND *CARDIOCERAS CANADENSE* WHITEAVES

T.P. Poulton[1]

Poulton, T.P., Jurassic (Oxfordian) ammonites from the Fernie Formation of Western Canada: a giant peltoceratinid, and Cardioceras canadense Whiteaves. In Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 396, p. 173-179, 1989.

Abstract

A new occurrence of a giant peltoceratinid ammonite is described from southern Alberta. It is closely associated with *Buchia concentrica* (Sowerby) and a small perisphinctid fragment, which are also figured. New material of *Cardioceras canadense* Whiteaves from its type locality in southeastern British Columbia is figured. Both occurrences are in the Oxfordian beds ('Green beds') of the Fernie Formation.

Résumé

De nouvelles observations faites dans le sud de l'Alberta ont permis de relever la présence d'une ammonite géante de type peltoceratinidé. Cette devinère est étroitement associée à *Buchia concentrica* (Sowerby) et à un petit fragment de périsphinctidé qui est également figuré. De nouveaux spécimens de *Cardioceras canadense* Whiteaves prélevés dans leur localité type dans le sud-est de la Colombie-Britannique sont figurés. Dans les deux cas, les spécimens observés se trouvaient dans les couches oxfordiennes ("couches vertes") de la formation de Fernie.

INTRODUCTION

The purpose of this report is twofold: first, to describe and illustrate the first occurrence in Canada, and possibly in North America, of a giant peltoceratinid ammonite (family Aspidoceratidae Zittel, 1895) and second, to illustrate new topotypes of the cardioceratid ammonite *Cardioceras canadense* Whiteaves. Both occurrences are from Oxfordian beds, the first from southwestern Alberta, the second from southeastern British Columbia. Both collections come from the 'Green beds' of the Fernie Formation.

Ammonites of the Tethyan family Aspidoceratidae are most uncommon in Canada where Upper Jurassic faunas are dominated by Boreal taxa, belonging mainly to the family Cardioceratidae Siemiradzki, 1891. In Canada, only *Physodoceras* sp. has been illustrated previously (Poulton et al., 1988). Elsewhere in North America the family is represented by *Peltoceras* from California and Mexico and *Aspidoceras* from Mexico, Texas and Cuba (summarized by Imlay, 1980).

Upper Jurassic perisphinctid and other ammonites have recently been described from southwestern British Columbia (Poulton et al., 1988), but Alaskan occurrences of two significant specimens were overlooked. They were described by Imlay (1981) as *Aulacosphinctoides* and *Subplanites*(?). These occurrences extend the range of these lower Tithonian taxa from Mexico and the Caribbean to Alaska. They may not be identical with the Canadian *Discosphinctoides*(?) aff. *D. neohispanicum* Burckhardt or *Lithacoceras*(?) respectively, both described by Poulton et al. (1988), but their close morphological similarities, probably similar or identical age, and paleobiogeographic significance are noteworthy.

Another giant ammonite, *'Titanites' occidentalis* Frebold, 1957 occurs in probably latest Jurassic basal beds of the Kootenay Formation at Coal Creek near Fernie, and a fragment that may be of the same species has been found north of Sparwood (Hamblin and Walker, 1979). Because of the presence of this other specimen, there has been confusion and speculation regarding the identification, age, and stratigraphic position of the ammonite described here for the first time, but already widely known among the specialist community. The two giant specimens are not to be confused.

The first specimens of *Cardioceras canadense* Whiteaves to be found since the original description in 1903 are figured and described, confirming the hitherto uncertain locality suggested for that original collection. This species had been considered a doubtful indicator of the presence of Oxfordian material because its locality was thought to be suspect, or possibly to involve transported material (Frebold, 1957).

SYSTEMATIC DESCRIPTIONS

Superfamily PERISPHINCTACEAE Steinmann, 1890

Family ASPIDOCERATIDAE Zittel, 1895

Subfamily PELTOCERATINAE Spath, 1924

Peltoceratinid ammonite, indet.

Plate 7.1, figures 1-3.

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Description. The specimen is ornamented with 14 pronounced ribs that are simple, straight, and continuous across the venter. The cross-section of each rib is gently rounded as are the intercostal spaces, which are about as wide as the ribs. The cross-section and strength of each rib are very regular on the smaller end of the whorl preserved, but the ribs become more subdued and irregular in strength and spacing toward the larger, adoral end. This specimen does not exhibit the tubercles or other knobs and modified ribbing on the body chamber that characterize most other macroconch peltoceratinids.

The cross-section of the shell is subquadrate, with gently rounded ventrolateral edges bordering a flattened narrow venter. The ribs are mildly strengthened along the ventrolateral rounded edges. The flanks are very gently rounded and gently convergent toward the venter.

Measurements. The small remaining portion of a giant outer whorl measures 120 cm along the venter, subtending a chord of 113 cm. Different calculations, derived from the ratios of various measurements made on the specimen itself and a scale drawing, result in approximations of the diameter of a circle which includes the fragmentary periphery preserved, varying from 2 to 3 metres. Most methods result in circular diameters between 200 and 240 cm, and the figure resulting from the best fit of the periphery of the specimen to a curve, results in a circular diameter of 216 cm. Because of post-mortem distortion resulting in a very uneven periphery , and accumulated error in gluing the individual fragments together in reconstruction, these approximations are crude.

Another Western Canadian giant perisphinctid, *'Titanites' occidentalis* Frebold, has an ultimate whorl height/diameter ratio of about 35 per cent, similar to that of several published peltoceratinid specimens (Arkell et al., 1957). Assuming a constant rate of expansion, the diameter of the giant peltoceratinid described here can be calculated using this ratio, to be have been about 178 cm, placing it amongst the largest ammonites known. Another (unfigured) fragment of the same giant ammonite is larger than any of the other pieces, and indicates a whorl height well in excess of its measurable 32 cm; this does not extend to either the umbilical or ventrolateral edges. Such a size is consistent with an approximate diameter of 1.78 m or larger. All of the pieces available are non-septate, indicating that the specimen is represented only by body chamber fragments.

Occurrence and age. This giant ammonite specimen was collected by the late H. Frebold 30 to 35 years ago, in the 'Green beds' of the Fernie Formation along Carbondale River, southwestern Alberta. Frebold hired a local blaster to use explosives to remove the specimen. It was then shipped to Ottawa where efforts to restore it were not completed, and the specimen was put into dead storage and assumed lost until now. Because of the character of the shipping container, the size of the specimen, and the lithology of the matrix, the specimen described here is almost certainly the one collected by Frebold. Only a small portion of a giant whorl, and a few other smaller pieces remain. How much of the giant ammonite was originally collected and shipped is not known. The remaining fragments were assembled by Roger Michie.

From various localities, the 'Green beds' have yielded lower Oxfordian *Cardioceras* and *Gollathiceras* species, and upper Oxfordian (or lower Kimmeridgian?) *Buchia concentrica* (Sowerby), as well as a rich variety of other fossils, including various bivalves, gastropods, belemnites, vertebrates and microfauna (Lambe, 1914; Frebold, 1957; Frebold et al., 1959; Poulton, 1984). The lower beds of the stratigraphically equivalent unit in the western interior U.S.A., i.e. the lower part of the Swift Formation (Reeside, 1919; Imlay, 1980), contain the upper Callovian ammonite *Quenstedtoceras collieri* Reeside as well as lower Oxfordian ammonites and the upper Oxfordian bivalve *Buchia concentrica*. An upper Callovian through Oxfordian range for the giant is thus permissible, the same range as the subfamily Peltoceratinae worldwide. *Buchia concentrica* (Sowerby) occurs in what is probably the same outcrop on Carbondale River, giving a late Oxfordian or early Kimmeridgian age for some of the beds, but not necessarily the same bed that yielded the giant.

The green and rusty ochre-coloured sandstone matrix of the specimen confirms the origin of the peltoceratinid as being in the 'Green beds'. There is only one outcrop of the 'Green beds' along Carbondale River from which the ammonite could have come. It is on the north bank, south of Hillcrest, about 1.6 to 1.8 km east of the bridge over Lynx Creek, about 49°27.5'N latitude, 114°23'W longitude and is shown in the southern part of the tightly deformed core zone of the Turtle Mountain Anticlinorium by Norris (1959; see also McLearn, 1929 [as "Castle River"]; Frebold, 1957; Price, 1962; Hall and Stronach, 1982; Hall, 1984). The beds are disturbed by faulting and folding and thicknesses cannot be measured accurately, but there are about 12 to 16 m of 'Green beds'. Fossils collected in 1958 by D.K. Norris from what must be the same outcrop (GSC locality 41490) include an indeterminable perisphinctid ammonite fragment (Pl. 7.1, fig. 4) and *Buchia concentrica* (Sowerby) (Pl. 7.1, figs. 5,6). Additionally H. Frebold (pers. comm. to D.K. Norris, 1960) identified *Cardioceras*(?) and belemnites. The last two taxa cannot be confirmed in the existing collections, and are missing. *Buchia concentrica* from this locality has been figured previously (Frebold, 1957, Pl. XXXVIII, figs. 4a,b; 1964, Pl. XLVII, fig. 7). These fossils come from the upper part of the 'Green beds'. Other fossils reported from this locality include the gastropod *"Turbo" femiensis* Frebold (1957; Hall and Stronach, 1982).

Superfamily STEPHANOCERATACEAE Neumayr, 1875

Family CARDIOCERATIDAE Siemiradzki, 1891

Subfamily CARDIOCERATINAE Siemiradzki, 1891

Genus *Cardioceras* Neumayr and Uhlig, 1881

Cardioceras canadense Whiteaves, 1903

Plate 7.1, figures 7-13.

Cardioceras canadense Whiteaves, 1903, p. 66, figs. 1a,b.

non Cardioceras canadense Whiteaves. Reeside, 1919, p. 20, Pl. XVII, figs. 5-11.

Cardioceras canadense Whiteaves. Frebold, 1957, Pl. XXIV, figs. 2a,b; Frebold, 1964, Pl. XLVII, figs. 3a,b.

?*Cardioceras* (*Vertebriceras*) *whiteavesi* Reeside. Imlay, 1981, p. 34, Pl. 7, figs. 4-6.

non Cardioceras (*Subvertibriceras*) *canadense* Whiteaves. Imlay, 1982, p. 38, Pl. 26, figs. 14-33.

Cardioceras (*Cawtoniceras*) *canadense* Whiteaves. Callomon, 1984, p. 156.

Occurrence. The present specimens were collected by D.W. Gibson on the northwest, upper slopes of Fernie Ridge, in outcrops on the old Hosmer road from Fernie (UTM co-ordinates: Zone 11, 438867) (GSC locality C-142226). This locality conforms well with that described for the holotype of the specimen (Whiteaves, 1903; Frebold, 1957), and its proximity to the trail from Fernie makes it highly probable that this was Whiteaves' original locality: "near the top of a ridge running North 20 degrees East and situated 2 1/4 miles [3.62 km] North 70 degrees East from Fernie, B.C., about 4,000 feet [1219] m above sea level".

Remarks. The holotype has been described well and figured repeatedly (Whiteaves, 1903, figs. 1,1a; Frebold, 1957, Pl. XXXIV, figs. 1,2; 1964, Pl. XLVII, figs. 3a,b; 1970, Pl. XXII, fig. 12) and no description is repeated here. It is noteworthy that neither the holotype nor the newly discovered topotypes exhibit well developed bifurcating secondary ribs, a characteristic feature of the subgenus *Cawtoniceras* (Arkell et al., 1957), of *Cardioceras (Cawtoniceras) cawtonense* Blake and Hudleston (1877), with which Callomon (1984) compared *C. canadense*, and of those specimens from the American Western Interior that were erroneously identified as *C. canadense* by Reeside (1919) and Imlay (1982). Bifurcation of a few secondary ribs can be seen vaguely on only two specimens (Pl. 7.1, figs. 7 and 11). The American species also contain much more finely spaced secondary ribs, and the connecting riblets between the ventrolateral nodes and the keel are stronger. There is, in the Canadian species therefore, a feebly developed, nearly smooth or weakly ornamented spiral band between the two (Pl. 7.1, figs. 9-12), as there is also between the lateral and ventrolateral rows of nodes (Pl. 7.1, figs. 9,11,13). The spiral, nearly smooth, bands are ornamented only with the very weak fading extensions of the nodes that lie in the umbilical direction from them. The secondary ribs at intermediate growth stages are nodes or tubercles, only slightly elongated radially, and the ventral ends of the primary ribs are also enlarged into nodes. Only in the largest growth stage seen (Pl. 7.1, fig. 7) is there a significant elongation of the weak secondary ribs.

One specimen from Alaska, identified probably erroneously as *C. (Vertebriceras) whiteavesi* Reeside by Imlay (1981, p. 34, Pl. 7, figs. 4-6) may be identical with *C. canadense*, especially in view of the variability in strength and spacing of the ventrolateral nodes/secondary ribs in *C. canadense* (compare Pl. 7.1, fig. 13 of this report with Pl. 7, fig. 5 of Imlay, 1981). However, identity cannot be firmly established on the basis of the single partial specimen from Alaska, which represents a different growth stage from those preserved in Canada.

In spite of the differences of *C. canadense* from the American species mentioned above, the general similarities probably justify their interpretation as approximate age-equivalents. The same holds true of the detailed differences from, but general similarities with, *C. cawtonense* and with other species mentioned below, so that the correlation with the upper *Maltonense* Subzone of the Middle Oxfordian *Densiplicatum* Zone (Callomon, 1984) is probably valid. Of several similar species worldwide, the closest to *C. canadense* with nearly smooth or very weakly ornamented spiral bands seems to be *C. schellwieni* Boden, 1911 from Lithuania and from the uppermost *Densiplicatum* or lowermost *Tenuiserratum* zones ("St. Ives Rock") of England (Arkell, 1941; Wright and Callomon, 1980). Also, close similarities exist with *Cardioceras (Maltoniceras) brightoni* Arkell (1941, 1942) from the same beds in England, although its primary ribs are stated to be entirely suppressed, in contrast to those of *C. canadense*.

The presence of a fragment reportedly undifferentiable from *C. canadense* from the Lilloett area, southwestern British Columbia (Reeside, 1919; Frebold, 1957), cannot be confirmed or disproven because it was never illustrated nor was any unique identifying number given to it. It is probably not the same specimen described as *C. lillooetense* by Reeside (1919) and Imlay (1981), which differs from *C. canadense* in the regularity of the ribbing and its continuity over the entire flank. "*Cardioceras (Subvertebriceras)* cf. *C. (S.) canadense* (Whiteaves)" reported by Frebold and Tipper (1975) from west central British Columbia differs in its continuity of primary and secondary ribs.

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PLATE I

PLATE 1

Figures 1-3. Peltoceratinid ammonite.

Figured specimen GSC 89748, from Carbondale River south of Hillcrest, Fernie map-area (82G), Alberta. Lateral view (adoral direction to the left) and oblique ventral and lateral views (adoral direction to the right), x0.155. Total (straight) length of specimen 113 cm.

Figure 4. Perisphinctid ammonite, indet.

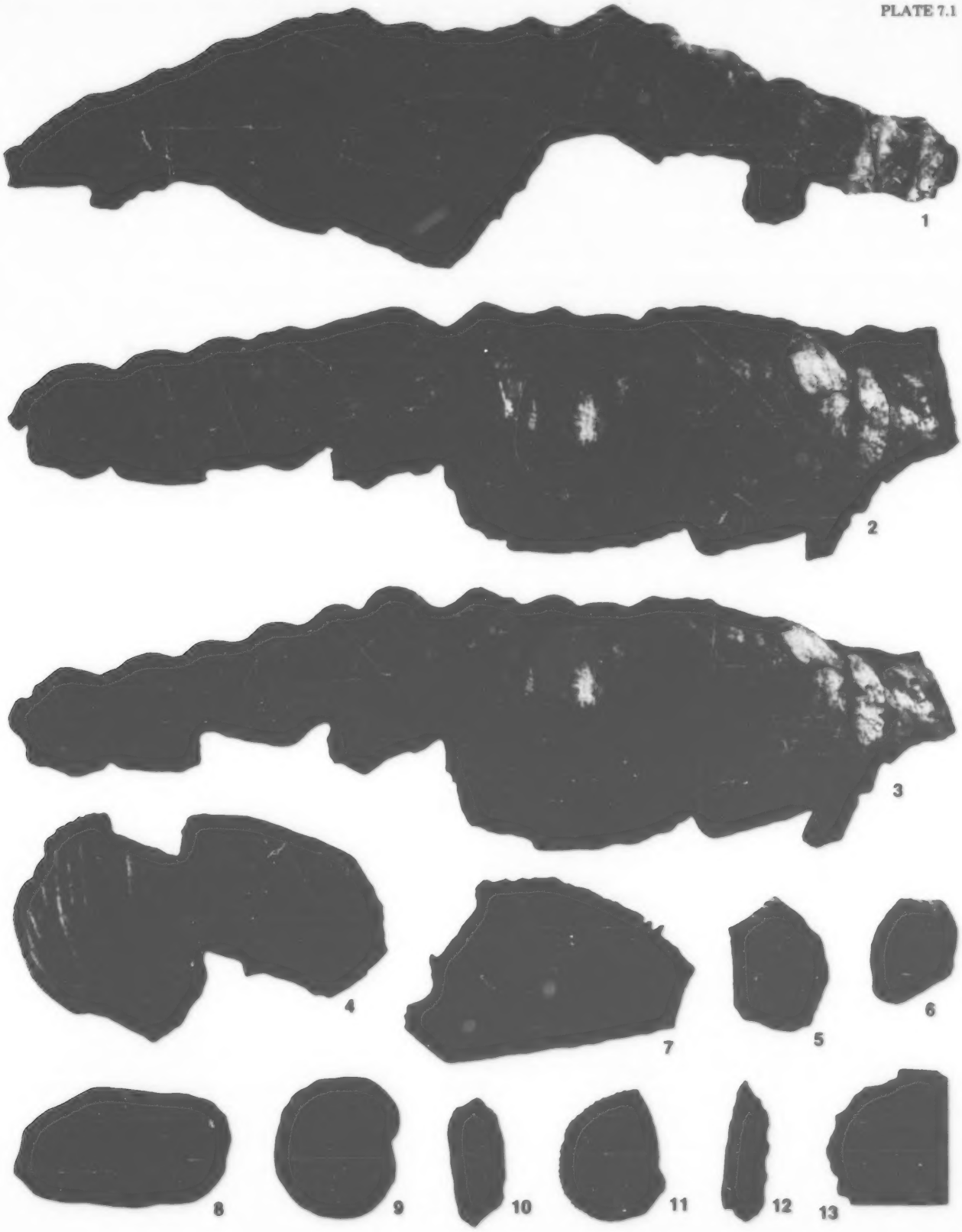
Small fragment (figured specimen GSC 87190) from GSC locality 41490; probably same locality as specimen in figures 1-3. Actual size.

Figures 5, 6. *Buchia concentrica* (Sowerby).

Figured specimens GSC 87191 and 87192 from GSC locality 41490; probably same locality as specimen in figures 1-3. Actual size.

Figures 7-13. *Cardioceras* (*Cawtoniceras*) *canadense* Whiteaves.

Latex casts of topotypes GSC 87193 to GSC 87197 (5 specimens) from GSC locality C-142226, Fernie Ridge northeast of Fernie, Fernie map-area (82G), British Columbia. Actual size.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NEW AND REVISED AMMONITES FROM THE UPPER CRETACEOUS NANAIMO GROUP OF BRITISH COLUMBIA AND WASHINGTON STATE

J.W. Haggart[1]

New and revised ammonites from the Upper Cretaceous Nanaimo Group of British Columbia and Washington State. In Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 396, p. 181-221, 1989.

Abstract

The ammonite species *Hypophylloceras (Neophylloceras) marshalli* (Shimizu), *Saghalinites maclurei* (White), *Gaudryceras striatum* (Jimbo), *G.* aff. *venustum* Matsumoto, *Desmophyllites* sp. cf. *larteti* (Seunes), *Damesites sugata* (Forbes), *Anagaudryceras politissimum* (Kossmat), *Eubostrychoceras* cf. *japonicum* (Yabe), and *Anapachydiscus* sp. nov. aff. *subtililobatus* (Jimbo) have been identified for the first time in collections from the Upper Cretaceous Nanaimo Group (Santonian - Maastrichtian) succession of southwestern British Columbia and Washington State. *Pseudoschloenbachia (Pseudoschloenbachia) umbulazi* (Baily) and *Ryugasella ryugasensis* Wright and Matsumoto, previously reported from the Nanaimo Group but never described, are figured for the first time. The stratigraphic distributions of *Gaudryceras denmanense* Whiteaves and *Desmophyllites diphylloides* (Forbes) in the Nanaimo Group are revised and restricted, based on re-examination of all available specimens of the two species.

Résumé

Les ammonites des espèces *Hypophylloceras (Neophylloceras) marshalli* (Shimizu), *Saghalinites maclurei* (White), *Gaudryceras striatum* (Jimbo), *G.* aff. *venustum* Matsumoto, *Desmophyllites* sp. cf. *larteti* (Seunes), *Damesites sugata* (Forbes), *Anagaudryceras politissimum* (Kossmat), *Eubostrychoceras* cf. *japonicum* (Yabe), et *Anapachydiscus* sp. nov. aff. *subtililobatus* (Jimbo) ont été identifiées pour la première fois dans des collections provenant de la succession (Santonien et Maastrichtien) du groupe de Nanaimo du Crétacé supérieur dans le sud-ouest de la Colombie-Britannique et de l'État de Washington. *Pseudoschloenbachia (Pseudoschloenbachia) umbulazi* (Baily) et *Ryugasella ryugasensis* Wright et Matsumoto, observées antérieurement dans le groupe de Nanaimo sans être décrites, sont figurées pour la première fois. Les répartitions stratigraphiques de *Gaudryceras denmanense* Whiteaves et *Desmophyllites diphylloides* (Forbes) dans le groupe de Nanaimo sont révisées et limitées, après réexamen de tous les spécimens disponibles des deux espèces.

INTRODUCTION

Details of the rich and diverse Santonian to Maastrichtian ammonite faunas of the Nanaimo Group, exposed on Vancouver Island and the adjacent Gulf Islands and San Juan Islands of British Columbia, Canada, and Washington State, U.S.A., were published comprehensively by Usher (1952) some time ago. Following Usher's work the Nanaimo fauna was studied by Jeletzky (in Muller and Jeletzky, 1970) and Ward (1976, 1978a), both of whom revised the molluscan biostratigraphy of the Nanaimo Group and listed several new taxa (see Muller and Jeletzky, 1970, Table II; Ward, 1976, Table 3.2). With the exception of several of the heteromorph species, however (Ward, 1976, 1978b; Ward and Mallory, 1977), no taxonomic analysis has been undertaken on the bulk of the Nanaimo Group fauna since that of Usher. Because new paleontological collections have been made since Usher's study, and a revised Nanaimo Group stratigraphic scheme has been proposed (Muller and Jeletzky, 1970; Ward, 1978a) a re-examination of the Nanaimo Group fauna is needed in order to fully understand its diversity and stratigraphic distribution.

In this paper, descriptions and illustrations are given for several new species identified by the writer in the collections of the Geological Survey of Canada in Ottawa. In addition, the taxonomic assignments of several of the specimens studied by Usher (1952) are revised and the stratigraphic distributions of several species that have biostratigraphic value elsewhere in the north Pacific region are clarified.

STRATIGRAPHY OF THE NANAIMO GROUP

The Upper Cretaceous Nanaimo Group succession outcrops on the eastern margin of Vancouver Island, and throughout the Gulf Islands of British Columbia and the San Juan Islands of Washington State (Fig. 8.1). Nanaimo Group strata have experienced relatively little tectonic and metamorphic modification and contain generally well preserved molluscan fossils. The locally abundant ammonites and inoceramid bivalves, two groups well known for their biostratigraphic value, have been used for correlation of the strata.

The Nanaimo Group has long attracted economic interest because of coal deposits, which occur at various levels in the stratigraphic sequence. Interpretations of the succession have been numerous and varied. Usher (1952), Muller and Jeletzky (1970), and Ward (1978a) give details of the development of the stratigraphic nomenclature of the group.

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Usher's correlation of Nanaimo Group strata (1952, Fig. 2) was questioned by McGugan (1962) on the basis of foraminiferal data, prompting a detailed re-examination of the succession by the Geological Survey of Canada. Muller and Jeletzky (1970) presented a modern interpretation of the Nanaimo Group litho- and biostratigraphic succession (Fig. 8.2), which has served as a cornerstone for successive paleoecological, sedimentological, and tectonic investigations. Ward (1978a, Fig. 2.2) refined the scheme, increasing the precision of local correlations (Fig. 8.2).

The writer has been unable to visit most of the localities discussed and has had to rely on the stratigraphic assessments of the original collectors. For most localities discussed by Usher (1952), assignment to the equivalent horizon within the stratigraphic scheme of Muller and Jeletzky has been relatively straightforward. Individual exceptions are noted in the text.

DISTRIBUTION OF NEW TAXA

The stratigraphic distributions of the ammonite species described in this paper are summarized in Figure 8.3, which includes a summary of the lithostratigraphy and molluscan zonal biostratigraphy of the Nanaimo Group developed by Muller and Jeletzky (1970) and Ward (1978a). Note that in

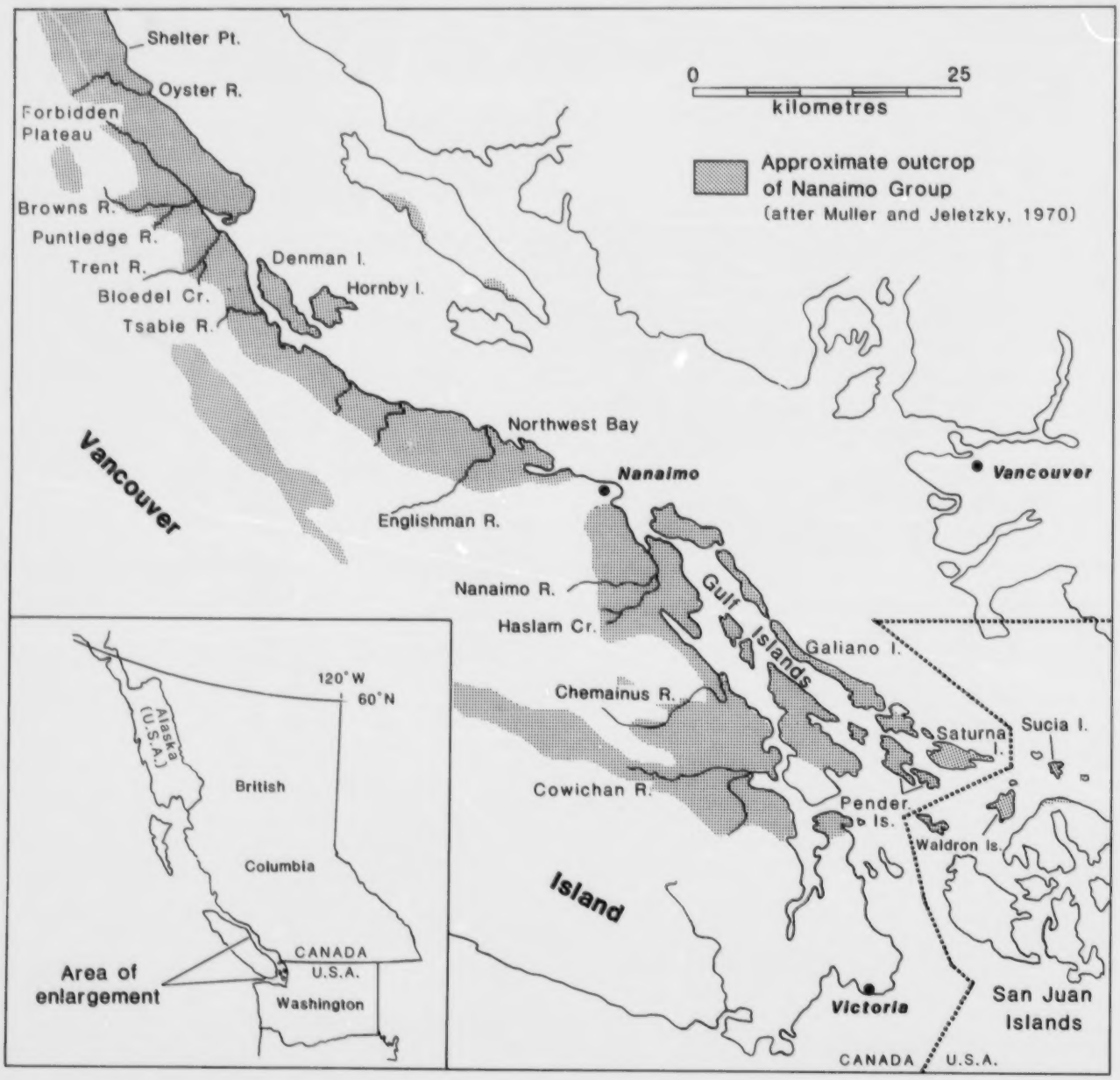

Figure 8.1. Outcrops of the Nanaimo Group, southern Vancouver Island and Gulf Islands, British Columbia, and San Juan Islands, Washington State, showing principal localities discussed in text.

the text molluscan zones and subzones are referred to by their trivial species name, e.g. Vancouverense Zone or Haradai Subzone. Several of the species included in Figure 8.3 are known from only one or, at most, a few, localities and thus have quite limited temporal distribution. Other species, however, such as *Damesites sugata*, *Gaudryceras striatum*, *Pseudoschloenbachia* (*Pseudoschloenbachia*) *umbulazi*, *Desmophyllites diphylloides*, and *Gaudryceras denmanense*, are represented by numerous specimens, collected from more extensive stratigraphic ranges within the Nanaimo Group succession. Given the extensive history of collecting of the Nanaimo Group, it is anticipated that further collecting will expand the stratigraphic ranges of all these species only minimally.

The author has collected *Baculites* sp. (GSC loc. C-140268) as well as other marine molluscs from the middle and upper parts of the Gabriola Formation on Galiano Island in the Gulf Islands indicating that much of the unit is of marine origin, rather than nonmarine as previously suggested (see Muller and Jeletzky, 1970). *Diplomoceras notabile* Whiteaves [=*D. cylindraceum* (Defrance)] is also reported to have been collected from the Gabriola Formation on Galiano Island (R. Best, pers. comm., 1985), as well as other islands in the Gulf Islands region (P. Ward, pers. comm., 1987), but these specimens have not been seen by the author.

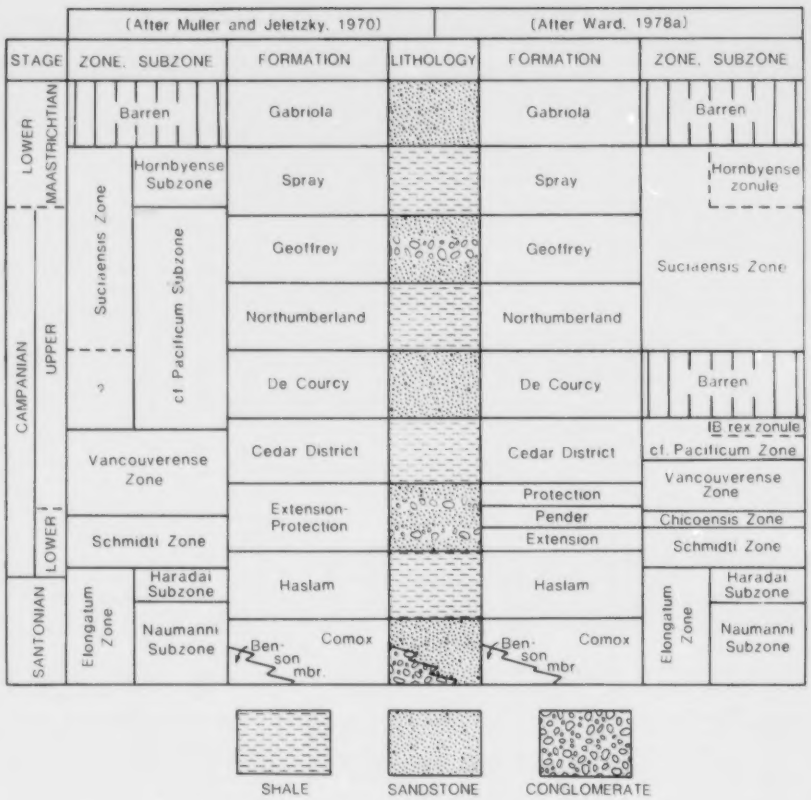

Figure 8.2. *Generalized stratigraphy of the Nanaimo Group, southwestern British Columbia and northwestern Washington State.* ***A****, after Muller and Jeletzky (1970);* ***B****, after Ward (1978a).*

This study highlights the potential of renewed taxonomic study of the Nanaimo Group fauna for improving local and regional biostratigraphic correlations. For example, all gaudryceratid ammonites from the Nanaimo Group had previously been described or noted as *Gaudryceras denmanense* Whiteaves, or *Gaudryceras* sp. The Nanaimo gaudryceratids actually comprise three distinct species, which are probably all from different stratigraphic horizons. These different species provide more precise local correlation and may also have biostratigraphic value elsewhere in the Upper Cretaceous of the north Pacific region. Similarly, Usher's (1952) concept of *Desmophyllites diphylloides* included several different morphologies; it is shown herein that *D. diphylloides* (s.s.) appears to be restricted to Campanian deposits in the Nanaimo Group, while the superficially similar *Damesites sugata* occurs in Santonian beds. Several of the newly recognized taxa are known from occurrences elsewhere in the Pacific and Tethys regions, especially California, Alaska, Japan, and New Zealand. Recognition of these species in the Nanaimo Group improves interregional correlation and documents the faunal similarity of these widely separated areas.

SYSTEMATIC PALEONTOLOGY

Conventions

Institution abbreviations

The following abbreviations of institutions are used: QCIM = Queen Charlotte Islands Museum, Skidegate, British Columbia; GSC = Geological Survey of Canada, Ottawa, Ontario; UWB = Burke Memorial Museum, University of Washington, Seattle; MCM = McMaster University, Hamilton, Ontario; UCLA = University of California, Los Angeles (now housed at Los Angeles County Museum of Natural History, Los Angeles); BM = British Museum (Natural History), London; USNM = United States National Museum, Washington, D.C.; CAS = California Academy of Sciences, San Francisco; UCMP = University of California Museum of Paleontology, Berkeley; UMUT = University Museum, University of Tokyo (= GT of earlier workers; see Ichikawa and Hayami, 1978).

Nomenclature

Open nomenclature follows the suggestions of Bengtson (1988).

Specimen dimensions

All dimensions are given in millimetres. See Table 8.1 for abbreviations used.

Morphological terminology

Morphological terms are those used in the Treatise on Invertebrate Paleontology (Moore, 1957). Quantifiers used to describe the size and shape of ammonite shells are often

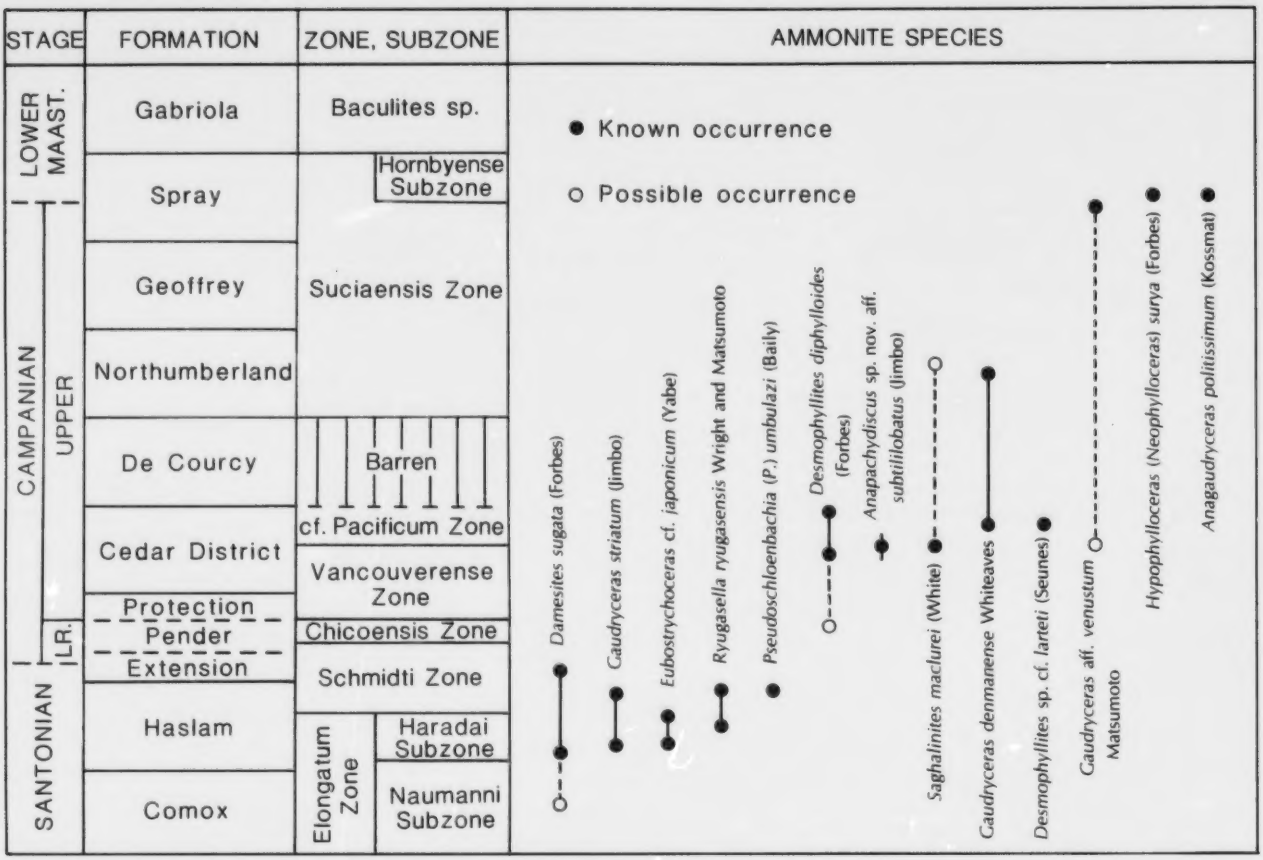

Figure 8.3. *Stratigraphic distribution of ammonite species discussed in this paper from the Nanaimo Group. Biostratigraphic zonation is modified after Ward (1978a).*

TABLE 8.1

Abbreviations used for specimen dimensions, morphological and sutural terminology

Specimen dimensions

Abbreviations

D = Diameter of entire whorl
Wb = Whorl breadth at given diameter
Wh = Whorl height at given diameter, measured from umbilical seam
U = Diameter of umbilicus
L = Length of preserved portion of heteromorph specimens, measured along growth axis
RI = Rib Index, on heteromorphs the number of ribs occurring in a distance equal to the whorl height at the midpoint of the interval counted

Sutural Terminology

E = External lobe
L = Lateral lobe
U = Umbilical lobe
I = Internal lobe

Morphological terminology

Size of shell

D < 35 mm : very small
35 mm < D < 75 mm : fairly small
75 mm < D < 125 mm : medium sized
125 mm < D < 250 mm : fairly large
D > 250 mm : very large

Width of umbilicus

U less than 8% of D : very narrow
U from 8% to 17% of D : narrow
U from 18% to 30% of D : fairly narrow
U from 31% to 40% of D : moderate
U from 41% to 50% of D : fairly wide
U from 51% to 65% of D : wide
U more than 66% of D : very wide

Whorl involution

Overlap less than 1/3 : very evolute
Overlap approximately 1/3 : fairly evolute
Overlap approximately 1/2 : moderate
Overlap approximately 2/3 : fairly involute
Overlap more than 2/3 : very involute

Whorl compression

Wb/Wh < 0.6 : very compressed
0.6 < Wb/Wh < 1.0 : fairly compressed
Wb/Wh approx. = 1.0 : as high as broad
1.0 < Wb/Wh < 1.5 : fairly depressed
Wb/Wh > 1.5 : very depressed

vague and their usage varies from worker to worker. In this paper the size quantifiers proposed by Matsumoto (1954, p. 246) are employed, with modification, as shown in Table 8.1.

Sutural terminology

The sutural nomenclature developed by Wedekind (1916; Kullmann and Wiedmann, 1970, p. 3-5) is used here and is shown in Table 8.1.

Curatorial designations

Fossil material from localities of the Geological Survey of Canada, the Queen Charlotte Islands Museum, the Thomas Burke Memorial Museum, the United States National Museum, and McMaster University, was utilized in this study. Localities cited in the text are listed with the institution abbreviation followed by the locality number, e.g. GSC loc. 102114 or UW loc. B-1245. A GSC locality number preceded with the letter C indicates that the collection is housed at the Institute of Sedimentary and Petroleum Geology in Calgary; collections from all other localities are housed in Ottawa, as of summer, 1988. Individual specimens cited in the text are referred to by their specimen number, preceded by the respective institution abbreviation, e.g. GSC 5803.

Some confusion exists in the literature regarding Geological Survey of Canada fossil localities discussed by Usher (1952, p. 46-48). Usher published his own numbering system for the collections he studied; unfortunately, his numbers are not recognized in the Geological Survey of Canada locality register. Although official GSC locality numbers have subsequently been assigned to Usher's informal designations, reference to his original locality numbers has persisted in more recent publications. As only additional confusion can result from the continued employment of Usher's system, a list of revised GSC designations is included as Appendix A.

The Cretaceous collections made by P.D. Ward (1976) and originally deposited in the Department of Geology, McMaster University, have subsequently been transferred to the Geological Survey of Canada, Ottawa, except for published type material (Ward, 1978b), which remains at McMaster University. (The author was unable to locate this material at McMaster University in September, 1986). These collections and their assigned GSC locality numbers are listed in Appendix B.

Suborder PHYLLOCERATINA Arkell, 1950

Family PHYLLOCERATIDAE Zittel, 1884

Genus *Hypophylloceras* Salfeld, 1924

Subgenus *Neophylloceras* Shimizu, 1934

Type species. Ammonites (Scaphites?) ramosus Meek, 1857, by designation of Shimizu, 1934 (see Wright and Matsumoto, 1954, p. 108-109).

Remarks. Shimizu's genus *Neophylloceras* has variously been considered within the synonymy of *Hypophylloceras*, as a subgenus of *Hypophylloceras*, or as an independent genus, depending on the importance attached by individual workers to the reduction of phylloid saddle terminations characteristic of the group. Birkelund (1965) concluded that the sutural differences between the two groups are undeniable, although minor, and she therefore treated *Neophylloceras* as a subgenus of *Hypophylloceras*. This practice has been followed by Matsumoto and Morozumi (1980) and is applied here.

Hypophylloceras (Neophylloceras) surya
(Forbes, 1846)

Plate 8.1, figures 1-3

1846 *Ammonites Surya* Forbes, p. 106, Pl. 7, figs. 10a, 10b.

1865 *Ammonites Surya* Forbes. Stoliczka, p. 115, Pl. 58, figs. 5a, 5b.

1895 *Phylloceras Surya* Forbes. Steinmann, p. 79, Pl. 5, fig. 1.

1895 *Phylloceras Surya* Forbes. Kossmat, p. 158, Pl. 16, figs. 1a, 1b, 1c.

1956 *Epiphylloceras mikobokense* Collignon, p. 24, Pl. 2, figs. 3, 3a, 3b; Pl. 4, figs. 5, 5a, 5b.

1959 *"Phyllopachyceras" surya* (Forbes). Naidin and Shimansky, p. 176, Pl. 15, fig. 3.

1977a *Phylloceras (Hypophylloceras) mikobokense* (Collignon). Kennedy and Klinger, p. 368, Pl. 12, fig. 1.

1985 *Phylloceras (Neophylloceras) surya* (Forbes). Henderson and McNamara, p. 42, Pl. 1, figs. 7, 8, 11, 12, Pl. 2, figs. 1, 2, Textfig. 2g.

1986 *Phylloceras (Hypophylloceras) surya* (Forbes). Stinnesbeck, p. 193, Pl. 7, figs. 5, 6.

Lectotype. BM C51075, the specimen figured by Forbes (1846, Pl. 7, figs. 10a, 10b) as designated by Henderson and McNamara (1985, p. 42).

Material. One well preserved specimen, GSC 84918 (GSC loc. 87096); upper part of Spray Formation, Hornby Island.

Description. Shell medium sized but may attain fairly large size, with wide umbilicus, gently convergent flanks, and sharply rounded venter. Umbilical wall steep, with rounded shoulder and, on last whorl, a distinct protruding shelf at mid-height.

Ornamentation of dense, coarse lirae which arise at umbilical shoulder, trend prorsiradiately across inner flank and turn to slightly rectiradiate orientation just before mid-flank. Flanks also ornamented with numerous short and long costae, occurring at intervals of five to seven lirae and oriented parallel to them. The longer of these arise at umbilical shoulder while the shorter are intercalated on inner flank; all are of equal strength on outer flank but disappear at venter. Costae are weakly developed on early growth stages (less than 30 mm diameter) and are restricted to inner part of flank. Above 40 mm diameter, costae increase in strength and occur across most of flank.

Suture not exposed.

Dimensions (mm).

Specimen	D	Wb	Wh	Wb/Wh	U(%)
GSC 84918	73.0	≈19	38.9	≈0.50	10.2(14)

Discussion. The wide umbilicus and the pattern of secondarily developed costae indicate identity with *Neophylloceras surya*. Two closely related species from the southwest Pacific, *Neophylloceras radiatum* (Marshall, 1926, p. 135, Pl. 19, fig. 7, Pl. 26, figs. 3, 4) and *N. marshalli* (Shimizu, 1935, p. 180, see Henderson, 1970, p. 3) may be early growth stages of this species. They differ from typical *H.* (*N.*) *surya* in their weaker costae, which are restricted to the inner part of the flank, and their more rectangular whorl-section. However, the two forms are quite similar in appearance to the smaller examples of *H.* (*N.*) *surya* figured by Stoliczka (1865, Pl. 58, fig. 5).

The Nanaimo example shows an unusual feature not commonly noted on other phylloceratids. This is the umbilical shelf, which begins to develop at a whorl height of 20 mm. Between the shelf and the umbilical seam the wall is overhanging. Faint lirae (not growth lines) can be discerned trending sharply forward across the upper part of the shelf but these disappear on the smooth, uppermost part of the umbilical wall. This feature was called the "spiral umbilical elevation" by Matsumoto (1942, p. 675), who noted that it is a prominent feature on *Neophylloceras subramosum* Shimizu but only weakly developed on other species. Anderson (1958, p. 181), as well, noted an "outward flare" on the umbilical wall of *Phylloceras vaculae* Anderson (= *N. ramosum fide* Matsumoto, 1959b) from California.

A single specimen of *Neophylloceras marshalli* was collected from the lower Maastrichtian on Hornby Island (see Jeletzky in Muller and Jeletzky, 1970, p. 57). The species is widespread elsewhere in the Pacific and Tethyan regions. In New Zealand, the species is considered to be Maastrichtian in age (Henderson and McNamara, 1985) and it also occurs in the lower Maastrichtian of Madagascar (Collignon, 1956) and South Africa (Kennedy and Klinger, 1977a), the Maastrichtian of Chile (Stinnesbeck, 1986), and the upper? Maastrichtian of Crimea (Naidin and Shimansky, 1959). Kilian and Reboul (1909) report the species as a rare component of the Snow Hill fauna in Antarctica and it is also known from Angola (Haughton, 1925) and Zumaya, Spain (Wiedmann, 1986).

Suborder LYTOCERATINA Hyatt, 1899

Family TETRAGONITIDAE Hyatt, 1900

Genus *Saghalinites* Wright and Matsumoto, 1954

Type species. Ammonites Cala Forbes, 1846, by designation of Wright and Matsumoto (1954, p. 110).

Remarks. The diagnosis and accompanying discussion given by Kennedy and Klinger (1977b, p. 167-168) serve to define the genus and distinguish it from other tetragonitids. Specimens from British Columbia show a more complex suture than examples from Greenland (figured by Birkelund, 1965) and South Africa (Kennedy and Klinger, 1977b), indicating close affinity with *Tetragonites*. The genus has a widespread distribution, occurring sparsely throughout the Indo-Pacific region as well as western Europe (Szász, 1982; Wiedmann and Boess, 1984; Kennedy and Summesberger, 1984, 1986; Kennedy, 1986a) and Greenland. Although representatives of *Saghalinites* were first recognized in Japan some time ago (see Shimizu, 1935), and possibly in California as well (Matsumoto 1959b, p. 154), the genus has not previously been identified in the Nanaimo Group.

Saghalinites maclurei (White, 1889)

Plate 8.1, figures 4-11; Figure 8.4

1889 *Ammonites Maclurei* White, p. 48, Pl. 7, figs. 2, 3.

cf. 1984a *Saghalinites teshioensis* Matsumoto, p. 27, Pl. 9, figs. 1-3.

Holotype. The specimen figured by White, USNM 20085 (herein Pl. 8.1, figs. 4-6), collected from Sucia Island, Washington State by E.W. McLure; probably Vancouverense Zone.

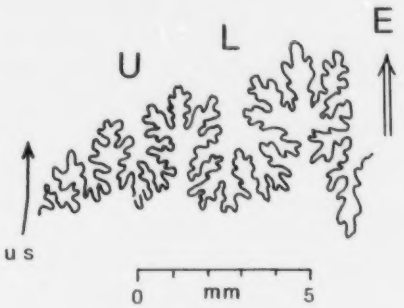

Figure 8.4. *Suture line of* ***Saghalinites maclurei*** *(White), GSC 84919 (GSC loc. 90888), at whorl height = 7.8 mm. US = umbilical seam; double arrow = trace of siphuncle.*

Material. USNM 20085, a quarter-whorl fragment of body chamber and accompanying mould. Fragment shows outer surface of inner shell layer and small portion of outer shell layer. Mould shows additional quarter whorl of body chamber, as well as crushed inner whorls. Fragment from GSC loc. 16461, a portion of mature body chamber, totalling approximately one third of a whorl. GSC 84919 and 84920 (both from GSC loc. 90888), are well preserved but slightly crushed internal moulds, which retain a small portion of shell. UW 56351 (UW loc. B-1955) is a well preserved internal mould.

Description. Shell fairly small, moderately evolute with subcircular to depressed-oval whorl section. Umbilical wall of early whorl slopes steeply; its broadly rounded shoulder becomes more abrupt in later growth stages. Whorl shows flattened subparallel flanks and broadly rounded venter, reaching greatest width near mid-flank.

Early whorls show no ornamentation other than very fine growth striae on outer shell and occasional prorsiradiate constrictions on mould. Fine striae, also interpreted as growth lines, are present on outer shell layer of living chamber, being most prominent on umbilical wall where they are gently prorsiradiate before turning sharply forward at umbilical shoulder; striae only weakly developed on venter. Outer two thirds of flank ornamented with very faint longitudinal elevations about a millimetre in width, much less in height, and separated by interspaces of similar width, the elevations becoming stronger in ventral region. Faint constrictions occur commonly in early growth stages (to

D = 20 mm), about six to eight per whorl, but are rare in intermediate stages. At latest growth stage represented (D >60 mm), strong constrictions occur with a frequency of three per quarter-whorl on the body chamber and form a shallow sinus on venter.

Dimensions (mm).

Specimen	D	Wb	Wh	Wb/Wh	U(%)
GSC 84919	-	12.4	12.1	1.02	-
GSC 84919	44.1	-	-	-	16.7(38)
GSC 84920	-	13.0	12.4	1.05	-
GSC 84920	46.3	-	-	-	17.7(38)
UW 56351	38.6	16.8	15.4	1.09	12.3(32)
UW 56351	51.8	-	18.1	-	18.3(35)
USNM 20085	-	21.7	20.4	1.06	-

Discussion. The evolute nature of the whorls and the rectangular and slightly depressed whorl section indicate the material belongs to *Saghalinites*. The longitudinal elevations were exaggerated on White's engraving of the holotype (1889, Pl. 7, fig. 2), appearing much stronger than in actuality. The early portion of the preserved body chamber of the holotype shows signs of an apertural shell break, which may have disrupted the subsequent development of constrictions. The body chamber fragment from GSC loc. 16461 includes a portion of the peristome. The last 50 mm of the body chamber includes several weak constrictions occurring at intervals of 10-15 mm, and a prominent and deep constriction on the internal mould adjacent to the peristome, which is manifest on the outer shell layer only as a very weak swelling. Several similar deep constrictions occur on the internal mould in the 35 mm adapical to the peristome. These constrictions appear similar to those described by Birkelund on mature examples of *Saghalinites wrighti* from West Greenland (cf. 1965, Pl. 3, fig. 1).

The Nanaimo material varies widely in whorl section outline, degree of involution, and steepness of umbilical wall. To compound the taxonomic difficulties, the limited number of specimens come from several different localities. As discussed below, the holotype was probably collected from the Cedar District Formation on Sucia Island; this specimen is very similar in preservation and morphology to the fragment from GSC loc. 16461, also from Sucia Island. Both these fragmentary specimens exhibit a more rounded whorl section and more numerous constrictions than seen on the much better preserved examples from Shelter Point. They also show the distinct longitudinal elevations figured prominently by White. However, the Shelter Point examples represent a slightly earlier growth stage and their lack of constrictions at this stage may be solely an ontogenetic factor. In addition, the preservation of the Shelter Point specimens is in coarse grained sandstone, rather than the mudstone of the holotype, and so the fine structure of the longitudinal elevations seen on the holotype may not be preserved. UW 56351, also from Sucia Island, appears as an intermediate form between the holotype and the Shelter Point specimens, showing very faint longitudinal elevations and a more rounded whorl section. Further collecting may show that the holotype and the specimen from GSC loc. 16461 are distinct from the other three specimens discussed above, but for now they are all treated as conspecific.

The Nanaimo material resembles certain other species from the Pacific region. *Lytoceras (Tetragonites) kingianum* Kossmat var. *involutior* Paulcke (1907, p. 174, Pl. 17, figs. 3, 3a, 3b, 4, 4a, 4b) from the upper Campanian of Patagonia (beds with *Hoplitoplacenticeras*) is more involute than typical examples of Nanaimo *Saghalinites* (Paulcke's measurements give an umbilicus = 32% of diameter), possesses a more rounded whorl section, and lacks constrictions. For these reasons Matsumoto and Miyauchi (1984, p. 53) considered the Patagonian forms as more closely related to *Tetragonites popetensis* Yabe, 1903 and suggested that *T. popetensis* and its allies are intermediate in form between *Tetragonites* and *Saghalinites*. The weak nature of many of the constrictions on the Nanaimo forms, as well as their absence at a similar growth stage as the specimens figured by Paulcke (1907, Pl. 17, figs. 3, 3a), suggest that this character may not be of value for generic differentiation. In its narrower umbilicus and rounded whorl section *L. (T.) kingianum* var. *involutior* approaches one of the Nanaimo examples, UW 56351 and these forms may represent a morphology transitional from *Tetragonites*, as previously suggested by Matsumoto and Miyauchi (1984).

Matsumoto (1959b, p. 153) suggested that *Lytoceras (Tetragonites) henleyense* Anderson (1958, p. 185, Pl. 12, figs. 5, 5a, Pl. 41, fig. 7) might be a California representative of *Saghalinites*. Anderson's specimens were found at CAS loc. 444 in Siskiyou County, California, in association with *Metaplacenticeras pacificum* (Smith), of late Campanian age. The holotype of *L. (T.) henleyense* is quite similar to an example of *S. maclurei* from Sucia Island, UW 56351, although it shows a whorl section and degree of involution intermediate between that specimen and the examples of *S. kingianus* var. *involutior* figured by Paulcke.

Saghalinites maclurei (White) appears very closely allied to a species recently erected by Matsumoto (1984a), *Saghalinites teshioensis*, from the Upper Campanian *Metaplacenticeras subtilistriatum* Zone of Hokkaido. Japanese specimens of *S. teshioensis* of similar size as *S. maclurei* have a slightly more depressed whorl section (Wb/Wh = 1.13 to 1.19), more evolute coiling, and a wider umbilicus (44% to 48% of D), although the crushed inner whorls of the holotype of *S. maclurei* suggest that this specimen may have been more evolute than the other Nanaimo Group examples. As in *S. maclurei*, there are fewer constrictions in the intermediate growth stage of *S. teshioensis*, and more in later growth stages. There is not yet enough material from both sides of the Pacific to conclude that *Saghalinites teshioensis* can be treated as a junior synonym of *Saghalinites maclurei* and the possibility exists that the Japanese and Canadian forms represent geographic subspecies.

The holotype, as well as specimen UW 56351, and the fragment from GSC loc. 16461 were all collected at Sucia Island. The latter two specimens came from the Cedar District Formation of Clapp and Cooke (1917) and although there is no locality information other than "Sucia Island" provided for the holotype either by White (1889), or on the accompanying identification slips, evidence summarized below suggests that it, too, came from the Cedar District Formation.

The stratigraphy of Sucia Island was first discussed by McLellan (1927) who gave a measured section – a 30 m sequence of coarse conglomerate with basal sand, succeeded by 215 m of sandy shale. This upper unit was first identified as the Haslam Formation by McLellan (1927) but subsequently recognized by Usher (1952) as a southerly exposure of the Cedar District Formation. Overlying the finer clastics of the Cedar District are several hundred metres of thick, cross-bedded sandstone with minor conglomerate and interbedded shale (McLellan, 1927). The uppermost of these strata were correlated by Waró (1978a, p. 413) with the De Courcy Formation of Clapp (1912); they have also been correlated with the Chuckanut Formation of McLellan (1927) by Vance (1975) and Johnson et al. (1986).

As far as the writer knows, no molluscs have been collected from the upper sandstones overlying the Cedar District Formation on Sucia Island. The Cedar District shales have so far provided numerous molluscan fossils and most of these have come from the horizons sampled by Usher. Ward (1978a, b) listed additional localities from the Cedar District Formation on Sucia Island, but the relative stratigraphic positioning of these was not given.

Ward (1978a) reported a greater thickness of coarse clastics underlying the Cedar District shales in the Sucia Island section than McLellan did, assigning them to the Protection Formation (op. cit., Textfig. 4). Like the coarse clastics in the highest part of the Sucia Island section, the Protection Formation is essentially barren of fossil invertebrates (op. cit., p. 413), although Ward did note one locality within the unit on the island, MCM loc. 161.

The poorly fossiliferous nature of the coarse clastics found both above and below the Cedar District shales on Sucia Island argues against their being the source of White's specimen. The matrix of the holotype is similar to that of other specimens collected from the Cedar District shales on Sucia Island, so White's specimen was probably obtained from the Cedar District Formation.

Based on the occurrence of *Hoplitoplacenticeras vancouverense* (Meek), *Pachydiscus* sp. cf. *jacquoti* Seunes, *Diplomoceras*? sp. indet., and *Pachydiscus neevesi* (Whiteaves), Jeletzky interpreted the age of these beds as early late Campanian (in Muller and Jeletzky, 1970). Ward (1978a) reported that the Vancouverense Zone extends downward below the Cedar District on Sucia Island, into the coarse clastics of the Protection Formation (MCM loc. 161). An early late Campanian age for the fossiliferous portion of the Sucia Island section thus seems well documented.

Usher (1952, p. 99) also identified late Campanian *Baculites occidentalis* Meek at Sucia Island, in a collection made by J. Richardson in 1874, but Jones (1963) has suggested that this single specimen was probably collected elsewhere. Ward (1978b), however, subsequently reported several examples of *Baculites occidentalis* collected from the highest fossiliferous exposures on Sucia Island. A baculitid comparable to *Baculites occidentalis* has been identified in Usher's collection from GSC loc. 16461 (Pl. 8.1, fig. 12), in the Vancouverense Zone; it is perhaps the oldest example of this species yet recovered from the Nanaimo Group.

The two other examples of *Saghalinites naclurei* discussed above, GSC 84919 and 84920, come from Shelter Point, GSC loc. 90888. Jeletzky (in Richards, 1975) tentatively assigned the Shelter Point fauna to the lower part of the upper Campanian portion of the Suciaensis Zone, based on the occurrence of *Pachydiscus* sp. cf. *P. suciaensis* and lack of *Nostoceras hornbyense*. Richards (1975) thus correlated these strata with the late Campanian to Maastrichtian Spray Formation of Usher (1952). A single specimen of *P. suciaensis* has since been collected from the Shelter Point outcrop (D. Nunnallee, pers. comm., 1987). Baculitids from GSC loc. 90888 at Shelter Point (not Denman Island as reported by Ward, 1978b, p. 1152) can be assigned to *Baculites subanceps pacificus* Matsumoto and Obata (= *B. anceps pacificus* of Matsumoto and Obata, 1963; revised by Howarth, 1965, p. 370), however, which occurs abundantly with *Metaplacenticeras pacificum* in California (Matsumoto, 1959a; Matsumoto and Obata, 1963) and on Denman Island, Nanaimo Group (Ward, 1978b). Furthermore, Ward (1978a) showed that *M.* cf. *pacificum* occurs below uppermost Campanian beds in the Nanaimo Group and has a short stratigraphic range that does not overlap the Suciaensis Zone (uppermost Campanian to lower Maastrichtian). The presence of both *P. suciaensis* and *Baculites subanceps pacificus* in the Shelter Point outcrop indicates that these species ranges overlap somewhat in the Nanaimo Group and also that the Shelter Point beds are perhaps better correlated with the slightly older Northumberland Formation than with the Spray Formation.

In summary, *Saghalinites naclurei* occurs in strata of late Campanian age in the Nanaimo Group.

Family GAUDRYCERATIDAE Spath, 1927

Genus *Gaudryceras* de Grossouvre, 1894

Type species. *Ammonites mitis* von Hauer, 1866, designated by Boule, Lemoine, and Thévenin, 1906.

Remarks. Matsumoto and Miyauchi (1984, p. 55) have noted that Campanian and Maastrichtian gaudryceratid ammonites show greater morphological differentiation and shorter stratigraphic ranges than older species of the group. Large examples of such Upper Cretaceous gaudryceratids are generally required for specific identification, however, as the early whorls (to an approximate diameter of 50 mm) are all similar in appearance. Due to a scarcity of well preserved material illustrating all ontogenetic stages, most gaudryceratids from the Nanaimo Group have been included within *Gaudryceras denmanense* Whiteaves, described in detail by Usher (1952). Examining new collections unavailable to Usher and preparing the specimens studied by Usher, the writer has distinguished three stratigraphically distinct species, from the upper Santonian, upper Campanian, and the lower Maastrichtian. The stratigraphic occurrences of two of these species in British Columbia agree very closely with reported occurrences of similar or identical forms in California, Alaska, and Japan, suggesting they may be biostratigraphically useful in the north Pacific region.

Gaudryceras denmanense Whiteaves, 1901

Plate 8.3, figure 1; Figure 8.5

1879 *Ammonites Jukesii*? Sharpe. Whiteaves, p. 111, Pl. 13, figs. 3, 3a, 3b.

1895 *Lytoceras Jukesii* Sharpe. Whiteaves, p. 129, Pl. 2, figs. 1, 2.

1901 *Lytoceras* (*Gaudryceras*) *Denmanense* Whiteaves. Whiteaves, p. 32.

1903 *Gaudryceras Denmanense* Whiteaves. Whiteaves, p. 329.

1952 *Gaudryceras denmanense* Whiteaves. Usher, p. 59 (part.), Pl. 4, figs. 1, 2.

1963 *Gaudryceras tenuiliratum* Yabe. Jones, p. 26, Pl. 9, Pl. 10, figs. 1-3.

1970 *Gaudryceras denmanense* Whiteaves. Jeletzky (in Muller and Jeletzky), p. 38 (part.).

non 1959b *Gaudryceras* (s.s.) cf. *denmanense* Whiteaves. Matsumoto, Pl. 37, figs. 2a, 2b.

Lectotype. GSC 5854, collected by W. Harvey in 1893, as designated by Usher (1952, p. 60); Cedar District Formation, Denman Island.

Figure 8.5. *Whorl section of* ***Gaudryceras denmanense*** *Whiteaves, GSC 10027, at whorl height = 33 mm.*

Material. GSC 5800 (figured by Whiteaves, 1879), juvenile collected by J. Richardson in 1871. Examples subsequently figured or described by Whiteaves and Usher include GSC 5854 (lectotype figured by Usher), 5854a (paralectotype figured by Usher), 5854b and 10027 (unfigured paralectotypes of Usher), all collected by W. Harvey in 1893. GSC 84922 (GSC loc. 7337), a mature example; east coast Denman Island. GSC 84923 (GSC loc. 15556), a poorly preserved specimen showing intermediate- and late-stage ornamentation; east coast Denman Island. GSC 84924 (GSC loc. 83908) includes slightly more than one half of the whorl and shows early- and intermediate-stage ornamentation on lower flanks; north shore Denman Island.

Description. Description of Usher (1952, p. 59-60) is adequate for early and intermediate growth stages (up to 90 mm), but larger individuals are markedly different, being more compressed with a high, nearly vertical, umbilical wall. Ribbing continues to coarsen in late growth stages, becoming more sigmoidal on flanks. Ribs become very sharp and high, with gently sloping adoral face and abrupt, nearly vertical, adapical face. Ribs are one third to one half as wide as interspaces and most arise on umbilical wall, but a few originate as intercalations at umbilical shoulder. Latest stage of growth shows six slightly wider and stronger ribs, spaced evenly; they are accompanied by pronounced deepening of the associated adapical interspace on outer flank and venter. Internal mould much smoother than outer shell surface.

Discussion. The morphology of *Gaudryceras denmanense* at all growth stages is now known and is distinctly different in juvenile and adult forms. Jones (1963) assigned large gaudryceratids from the upper Campanian of southeast Alaska to *G. tenuiliratum* Yabe noting the distinct, late stage ribbing of the Alaskan forms. He distinguished the Alaskan specimens from *G. denmanense* by the lack of primary and secondary ribs in the late growth stage of *G. denmanense*, as well as the apparently more sinuous nature of the ribbing on the Alaskan forms. Matsumoto and Miyauchi (1984, p. 58) questioned Jones' assignment, suggesting instead that at least some of the Alaskan material was closer to *G. denmanense*. In a subsequent paper, Matsumoto (1984b, p. 4) suggested that one of Jones' specimens (Jones, 1963, Pl. 9, figs. 1-3) resembled the Japanese species *Gaudryceras mamiyai* Matsumoto and Miyauchi and the other (Jones, 1963, Pl. 10, figs. 1-3) *Gaudryceras tombetsense* Matsumoto. One of the specimens figured by Jones (1963, Pl. 9) appears quite similar to the large example from the Nanaimo Group figured herein. Comparison of illustrated material from both regions suggests that the Alaskan specimens fall within the morphological range of *G. denmanense*. *Gaudryceras tombetsense* and *G. mamiyai*, although closely related to *G. denmanense*, are sufficiently distinct to be considered different species.

Matsumoto (1959b, p. 144) referred a juvenile gaudryceratid from the lower half of the section of the Chico Formation at Big Chico Creek, northern California (*Baculites capensis* Zone of Haggart, 1984a), to *Gaudryceras* cf. *denmanense*. Jones noted (1963, p. 28), that this specimen is probably best referred to *G. tenuiliratum* Yabe.

All specimens assigned to the revised description of *G. denmanense* have been collected from the northwest and east sides of Denman Island or from the nearby Norris Rocks, south of Hornby Island. A specimen collected by Usher from the Qualicum Formation (= Extension-Protection Formation of Muller and Jeletzky, 1970) in Northwest Bay (GSC loc. 16488) was referred by him to *G. denmanense*; this poorly preserved juvenile can only be assigned with certainty to *Gaudryceras* sp. Muller (in Muller and Jeletzky, 1970, Textfig. 11) mapped the east side of Denman Island and the Norris Rocks localities within the De Courcy and Northumberland formations. The shale matrix associated with all the specimens suggests the Northumberland as the more likely unit for their origin; this is also consistent with the nonfossiliferous nature of the lower De Courcy (Muller and Jeletzky, 1970, p. 27). It should be noted, however, that the mapping of Muller suggests that the Norris Rocks locality may be within the De Courcy. Jeletzky (in Muller and Jeletzky, 1970, p. 56-57) has assigned the Northumberland Formation to the upper Campanian cf. Pacificum Zone. The locality on the northwest side of Denman Island, GSC loc. 83908, is in the upper part of the Cedar District Formation (field notes of J.A. Jeletzky) from beds also containing *M.* cf. *pacificum*. Thus, *G. denmanense (s.s.)* is restricted to beds of late Campanian age in the Nanaimo Group.

Gaudryceras striatum (Jimbo, 1894)

Plate 8.2, figures 1-11

1894 *Lytoceras striatum* Jimbo, p. 181, Pl. 22, figs. 6, 6a, 6b.

1903 *Gaudryceras striatum* (Jimbo). Yabe, p. 31, Pl. 4, figs. 6, 6a, 6b.

1903 *Gaudryceras striatum* var. *picta* Yabe, p. 33, Pl. 4, figs. 6, 6a, 6b.

1941 *Gaudryceras striatum* (Jimbo). Matsumoto, p. 23, figs. 2d, 2e.

1970 *Gaudryceras denmanense* Whiteaves. Jeletzky (in Muller and Jeletzky), p. 38 (part.).

Holotype. UMUT MM7493 [=GT I-116] by monotypy as noted by Matsumoto (1963).

Material. GSC 84925 (GSC loc. 77419), whole specimen, partly crushed, showing surficial ornamentation and internal mould; basal Haslam Formation, Trent River. GSC 84926 (GSC loc. 64939), slightly less than half a whorl showing characteristic ribbing of early and intermediate growth stages; Haslam Formation, Haslam Creek. GSC 84927 (GSC loc. 102113), mostly complete, small; Haslam Formation, Puntledge River. GSC 84928 (GSC loc. 102111), fragment of large body chamber; Haslam Formation, Tsable River (P. Ward, pers. comm., 1986). UW 56367 (UW loc. B-4802), well preserved mould showing one side of large whorl; Haslam Formation, Trent River. All from Elongatum Zone. GSC 90744 (GSC loc. C-127611, Haslam Formation, Mt. Prevost), a flattened mould from the Schmidti Zone.

Description. Shell very evolute, expanding slowly in early growth stages, becoming moderately evolute and expanding more quickly in later stages. Whorl nearly as high as broad in middle growth stage (D = 50 mm), becoming higher than broad in late stage, with greatest width occurring just below mid-flank. Umbilical wall sloping, steepest in intermediate growth stage (25-50 mm diameter), but with rounded shoulder. Venter broadly rounded in early growth, moderately so in intermediate stage and narrowly arched in the adult.

Whorl surface covered with dense fine sigmoidal lirae, which bend sharply forward on umbilical wall and shoulder, then slightly backward, traversing inner flank radially. On outer flank, lirae bend very slightly forward, crossing venter in broad, adorally convex arc. Most lirae arise on umbilical wall but a few are intercalated on inner flanks. Lirae not visible on internal mould.

At approximate diameter of 20 mm, periodic major ribs appear, approximately five per whorl, associated with very shallow constrictions parallel to lirae. Ribs arise in umbilical region and continue across flanks to venter. Major ribs are low and flat, twice as wide as high and generally smooth, with faint striae (growth lines) noted on surface of some examples. Major ribs increase in frequency and are somewhat reduced in relative height during subsequent growth with approximately ten occurring on the last half of the adult body whorl.

Suture not well exposed.

Dimensions (mm).

Specimen	D	Wb	Wh	Wb/Wh	U(%)
GSC 84927	48.7	19.7	19.5	1.01	17.7(36)
GSC 84925*	72.2	23.8	29.4	0.81	28.1(39)

*slightly compressed due to compaction

Discussion. All specimens, except UW 56367, are fairly small to intermediate in size, less than 75 mm in diameter, and the preserved body chamber of GSC 84925 occupies 320° of a whorl. The pattern of ornamentation on the later whorls of this species is quite distinct from that of other gaudryceratids from the Nanaimo Group. Individuals can readily be distinguished from *Gaudryceras denmanense* by their smaller size, more evolute coiling and more compressed whorl, more sloping umbilical wall, and fine lirae at all growth stages.

Jimbo's (1894) brief original description, based on a single individual of 47 mm diameter, was revised and supplemented by Yabe (1903) using additional material from the type locality. The ribbing typical of Yabe's figured example of the species (1903, Pl. 4, fig. 5) is only faintly depicted in Jimbo's figure, which represents a slightly earlier growth stage. Yabe (1903, p. 32) noted the same increase in frequency of the periodic major ribs on the Japanese material that is seen on the Canadian specimens and his description suggests that the major ribs are present from the earliest growth stage. On the Canadian material, however, the first major ribs are noted at a diameter of approximately 22 mm although shallow constrictions, approximately four per whorl and associated with very slight swellings on the outer shell surface, are noted on even earlier growth stages, down to a diameter of about 14 mm. This difference in the timing of first appearance of the major ribs is not considered of specific or even subspecific importance.

D. Nunnallee collected a large specimen, 115 mm in diameter, from the Haslam Formation along Trent River (Pl. 8.2, fig. 11), which includes both the late stage ornamentation seen on GSC 84928 (with somewhat more frequent ribbing than that specimen) as well as the earlier growth stage ornamentation of GSC 84925 and GSC 84926.

Yabe's variety of *Gaudryceras striatum*, var. *picta*, is based on a single specimen and differentiated from the typical form by broader whorls and a quadrate whorl section, which inflates substantially during growth. In all other characteristics the variety is identical to the type series of *G. striatum (s.s.)*. No quadrate whorl sections occur in the limited Canadian material but Yabe's values for the relative breadth and height of the whorl of *G. striatum* var. *picta* are quite close to those of the Canadian specimens as well as the typical form. As the var. *picta* is almost identical to *G. striatum* in most details of morphology and ornamentation it is herein included within *G. striatum*.

The characteristic periodic major ribs which appear in the early growth stages of *G. striatum* from the Nanaimo Group and Hokkaido (cf. Yabe, 1903, Pl. 4, fig. 3) are similar to those appearing on *G. amapondense* from the upper Santonian to lower Campanian of South Africa (van Hoepen, 1920, Pl. 24, figs. 4, 5). The writer considers *G. amapondense* as distinct from *G. denseplicatum* (Jimbo) (contrary to Kennedy and Klinger, 1979, p. 140 and 142, but supported in p. 129 of that publication) because van Hoepen's specimens do not appear to develop the coarser, fold-like ribs characteristic of *G. denseplicatum* at similar growth stages (cf. Kennedy and Klinger, 1979, Pl. 5, figs. 1, 2 and Pl. 6, fig. 2). The holotype of *G. amapondense* as figured by van Hoepen appears badly weathered and it is thus difficult to ascertain whether the fine lirae (characteristic of all growth stages of *G. striatum*) continue to develop in its later growth stages. The Canadian *G. striatum* also shows somewhat more sigmoidal ribs, which bend slightly forward on the outer flank and venter; ribs on *G. amapondense* appear to arc gently backward across the ventral region.

Gaudryceras hamanakense Matsumoto and Yoshida (1979, p. 68, Pl. 10, figs. 1-3, Pl. 11, figs. 1, 2), from the Maastrichtian of Hokkaido, is apparently similar to *G. striatum*, having periodic major ribs and fine lirae, which persist on the outer part of the whorls throughout growth. In *G. hamanakense* the lirae are distinctly coarser around the umbilical margin than in *G. striatum*, bifurcating and intercalated with finer and denser lirae on the outer flank and venter in typical *Vertebrites* pattern, in distinct contrast to *G. striatum*. *Gaudryceras hamanakense* is also somewhat more evolute (umbilicus = 47-50% of diameter) and more depressed.

Gaudryceras alamedense Anderson (*non* Smith) is also closely related. Its type locality is in the upper Guinda or lower Forbes Formation of central California (Sims et al., 1973), indicating the upper Santonian (Matsumoto, 1960; Haggart, 1984a; Haggart and Ward, 1984). The early whorls

of Anderson's figured example (1958, Pl. 41, figs. 5, 5a) show very similar ribbing to the Nanaimo specimens. At a diameter of about 45 mm, the ribs appear to coarsen and become more widely spaced, in contrast to the Nanaimo forms, which retain their fine, hair-like lirae on the larger whorls. Anderson's figures show the whorl as slightly less rounded in cross-section.

Gaudryceras varicostatum van Hoepen (1921, p. 7, Pl. 2, figs. 10-12, Textfigs. 3, 4) shows slightly coarser lirae in the early growth stage, at approximately 30 mm diameter. Larger examples of this species show an increase in the coarseness of lirae during ontogeny but, except for a few collar-like ribs associated with constrictions on the later whorls, no development of flattened and strengthened ribs (Kennedy and Klinger, 1979, p. 134, Pl. 3, figs. 3a, 3b, Pl. 4, Pl. 7, figs. 2a, 2c, Pl. 14, fig. 11).

Gaudryceras striatum is also closely allied to *G. tenuiliratum* Yabe from the Coniacian and Santonian of Japan and Sakhalin Island especially its variety *ornata* Yabe (1903, p. 24, Pl. 3, figs. 2a, 2b). The writer has collected *G. tenuiliratum* from lower and middle Santonian strata of the Chico Formation in California (unpublished data). *Gaudryceras striatum* differs from *G. tenuiliratum* by its slightly more evolute and more compressed whorl and by retention of dense, fine ribbing at all growth stages (cf. Matsumoto and Miyauchi, 1984, Textfig. 8 and this paper, Pl. 8.2, fig. 11).

According to Matsumoto (1963), *G. striatum* occurs in the Campanian of Japan. It is also present at several localities in northern California (writer's collections). Occurrences along Sand Creek and Antelope Creek, in the Forbes and Chico formations respectively, are in the *Sphenoceramus schmidti* Zone, interpreted as upper Santonian to lower Campanian. Specimens from the Hooten Gulch Mudstone member (Haggart, 1986) of the Redding Formation along Clover Creek (equal to Member IV of Popenoe, 1943) and along Old Cow Creek (equal to Member VI of Popenoe, 1943) are fragments of the flanks and show the same pattern of lirae and ribs as the figured Nanaimo material, although the frequency of ribbing is greater, similar to the specimen collected by D. Nunnallee.

Gaudryceras aff. *venustum* Matsumoto, 1984

Plate 8.1, figures 13, 14; Plate 8.3, figures 2, 3

non 1864 *Ammonites Hoffmannii* Gabb, p. 65, Pl. 11, fig. 13a, Pl. 12, figs. 13, 13a.

1903 *Pleuropachydiscus Hoffmannii* (Gabb) var. Whiteaves, p. 352.

1952 *Gaudryceras* sp. Usher, p. 60.

cf. 1984b *Gaudryceras venustum* Matsumoto, p. 5, Pl. 3, figs. 1, 2.

Material. GSC 5951, collected by L.F. Newcombe in 1896, fragment of body chamber of a small individual; "Sucia Islands", probably Cedar District Formation. GSC 10028 (GSC loc. 15565), collected by J.L. Usher in 1945, portion of phragmocone of large individual, greater than 125 mm in diameter, and portion of earlier whorl; Spray Formation, Hornby Island, upper part of cf. Pacificum Zone.

Description. Shell attains very large size and is moderately evolute with whorl higher than wide, reaching greatest width just above umbilical shoulder. Umbilical wall vertical with sharply rounded shoulder on younger whorls. Flanks of intermediate growth stage (at whorl height of 30 mm) ornamented with numerous fine lirae and periodic weak ribs. Weak ribs flattened, approximately six per quarter-whorl, accompanied by somewhat wider but very shallow constrictions. Fine lirae are shorter but sharper than ribs, separated by interspaces twice as wide as high.

Most lirae and all ribs arise on umbilical wall just above seam, but a few lirae originate as intercalations on inner flanks. Lirae and ribs are prorsiradiate on upper umbilical wall, turn and cross to mid-flank in gently rursiradiate arc, then turn gently forward on outer flank to cross venter in an almost straight line.

Adult body chamber (at whorl height greater than 125 mm) loses ribs and associated constrictions and is ornamented solely with numerous and crowded, fine, sharp lirae. Most of these originate on the very oblique umbilical wall, but a few arise as intercalations on innermost flank. Lirae trace broad sweep across inner and middle parts of flank, are convex toward aperture, and turn slightly forward on outermost preserved part of whorl.

The suture is not exposed.

Dimension (mm).

Specimen	Wb	Wh	Wb/Wh
GSC 5951	29.2	33.8	0.86

Discussion. Anderson (1938, p. 184, 186) discussed the taxonomic status of Gabb's specimens of *Ammonites Hoffmannii*, noting that the holotype is lost, and concluded that Gabb's original specimens were a composite group that included at least two distinct species. He designated a lectotype for *A. hoffmannii* and transferred the species to the genus *Puzosia*, giving a stratigraphic occurrence in the Albian of California (Neptune and Packard zones). Whiteaves' variety of *hoffmannii*, based on a single specimen and figured here in Plate 8.1, figures 12 and 14, bears only a superficial resemblance to *A. hoffmannii* Gabb, differing from Gabb's figured example in its much weaker and less numerous constrictions, and its more numerous fine lirae on all parts of the whorl. In addition, the ornamentation of Gabb's species is more prominently prorsiradiate in its orientation, in contrast to the Canadian species, which shows a rursiradiate to rectiradiate pattern across most of the flank.

In the degree of whorl evolution, as well as the pattern of dense, weak lirae and periodic major ribs the Nanaimo specimens agree closely with *Gaudryceras venustum* Matsumoto from the upper Maastrichtian of Hokkaido. That species appears much more compressed than the Nanaimo one, however, although this may be due, in part, to compaction (Matsumoto, 1984b, p. 5). *Gaudryceras venustum* also has frequent major ribs on the adult body chamber in addition to its fine and dense lirae and weak riblets (called subcostae by Matsumoto). Usher (1952, p. 60) noted the superficial resemblance of the dense, sharp ribbing of the outer whorl of GSC 10028 to that occurring on *Gaudryceras mite* von Hauer (1866, p. 305, Pl. 2, figs. 3, 4). Further preparation allowed earlier parts of the whorl to be extracted from the matrix of the Canadian specimen, clearly showing the presence of numerous periodic major ribs, and indicating its distinctiveness from von Hauer's species.

The Canadian material bears some resemblance to *Gaudryceras navarrense* Wiedmann (1962, p. 158, Pl. 9, fig. 3; Textfig. 16), from the Campanian of northern Spain. It differs from that species by its finer and denser lirae, higher frequency of ribbing, and infrequent to rare occurrences of intercalations or bifurcations on its flanks.

GSC 5951 was collected from "Sucia Islands". No other locality data for this specimen are available. Youngest fossiliferous strata yet identified on Sucia Island contain faunal elements of the lower upper Campanian Vancouverense Zone (Ward, 1978a). More reliable data are available for Usher's specimen. According to his fieldbook (1945-1), GSC 10028 came from Hornby Island, between Shingle Spit and Phipps Point. Usher referred these strata to the upper Lambert Formation, and they have been more recently mapped as Spray Formation (Muller in Muller and Jeletzky, 1970, Fig. 11). Muller and Jeletzky divided the Spray into lower and upper parts, separated by a distinctive sandstone which outcrops near Collishaw Point on Hornby Island (1970, p. 30-31), stratigraphically above Usher's locality. According to Muller and Jeletzky, the sandstone also seems to mark the boundary between the lower part of the Suciaensis Zone and the overlying Hornbyense Subzone. Usher's specimen was probably collected from the upper beds of the lower portion of the Suciaensis Zone, of latest Campanian age (Jeletzky, in Muller and Jeletzky, 1970, p. 56-57), slightly younger than occurrences of *Gaudryceras denmanense* on nearby Denman Island. Further collecting is required to verify the possible lower upper Campanian occurrence of the species on Sucia Island.

Genus *Anagaudryceras* Shimizu, 1934

Type species. *Ammonites Sacya* Forbes, 1846.

Kennedy and Klinger (1979) reviewed the nomenclatorial problems associated with the type material of the genus and provided a generic diagnosis. Approximately twenty proposed species of *Anagaudryceras* of middle Albian to Maastrichtian age were listed by Collignon in his summary (1956) to which Kennedy and Klinger (1979) added five. There are also the following recently erected species: *Anagaudryceras matsumotoi* Morozumi (1985, p. 29, Pl. 9, fig. 1, Textfig. 7; = *A. ryugasense* Matsumoto, 1942, a *nomen nudum*), Maastrichtian, Japan; *A. nanum* Matsumoto (1985, p. 25, Pl. 5, figs. 1-4), lower Campanian, Japan; *A. seymouriense* Macellari (1986, p. 10, Textfigs. 9.1-9.6; 10.1-10.4), upper Maastrichtian, Antarctic Peninsula; and *A. tetragonum* Matsumoto and Kanie (1985, p. 29, Pl. 5, figs. 9-11), Maastrichtian, Japan. As has been stressed by previous workers (i.e., Kennedy and Klinger, 1979; Henderson and McNamara, 1985) many taxa assigned to *Anaguadryceras* are based on single specimens, juvenile whorls, poorly preserved material, or a combination of all three, and are likely conspecific with other forms. An extensive review of the genus is required to establish its limits and specific composition.

Anagaudryceras politissimum (Kossmat, 1895)

Plate 8.6, figure 10

1895 *Lytoceras (Gaudryceras) politissimum* Kossmat, p. 128, Pl. 15, figs. 7a, 7b, 7c.

cf. 1909 *Lytoceras (Gaudryceras) politissimum* Kossmat. Kilian and Reboul, p. 14, Pl. 1, figs. 7, 8.

cf. 1979 *Anagaudryceras politissimum* (Kossmat). Kennedy and Klinger, p. 154, Pl. 5, fig. 3.

1985 *Anagaudryceras politissimum* (Kossmat). Henderson and McNamara, p. 46, Pl. 1, figs. 9, 10, Textfig. 4d.

1985 *Anagaudryceras politissimum* (Kossmat). Matsumoto, p. 23, Pl. 3, figs. 1-6, Pl. 5, figs. 5-8 (with synonymy).

1986 *Anagaudryceras* cf. *politissimum* (Kossmat). Stinnesbeck, p. 194, Pl. 7, fig. 9, Pl. 8, fig. 1, Textfigs. 18, 19.

Holotype. The original of Kossmat's figured specimen (Pl. 15, figs. 7a, 7b, 7c) from the upper Trichinopoly Group of southern India (by monotypy).

Material. GSC 90743 (GSC loc. 103852), a partially preserved whorl with one side exposed and retaining some original shell; upper part of Spray Formation, Hornby Island, Maastrichtian.

Description. Coiling very evolute with rounded whorl section, rounded and shallow umbilical wall. Whorl section depressed (Wb/Wh = 1.25) at whorl height of 10 mm, becoming somewhat compressed on subsequent coils. Body chamber occupies one full whorl (360°). Latest preserved part of body chamber shows a coarsening of lirae and crowding of constrictions in the last 15 mm. Surface of whorl covered with dense, fine hair-like lirae arising at umbilical seam and trending prorsiradiately across umbilical wall and innermost part of flank. At approximate whorl height of 7 mm, lirae on innermost part of flank begin to coarsen slightly, forming weak riblets diminishing in strength on outer part of flank. Deep and strong constrictions run parallel to lirae, approximately four per whorl, each associated with a stronger, elevated rib ("collar-ribs" of Kennedy and Klinger, 1979), also covered with lirae. Strong, more widely spaced lirae occur on inner flank of later whorls, but their strength diminishes on outer flank and venter where only hair-like lirae occur. Constrictions on later whorls are more frequent but weaker and the associated ribs form low and broad undulatory swellings on outer part of flank and venter; constrictions and lirae are prorsiradiate across flank, weakening on venter.

Suture only partly exposed, showing complexly subdivided elements.

Discussion. Most known occurrences of *Anagaudryceras politissimum* are represented by single, or a few, specimens, thus the degree of population variability in one region is difficult to assess. Kossmat's figured specimen of *Gaudryceras politissimum* is similar to the Canadian form in its strongly compressed whorl section, but is slightly more involute than the latter example. The specimen figured by Henderson and McNamara (1985) is close to the Canadian form in degree of whorl evolution, whorl compression, and roundness of the venter, while the example figured by Kennedy and Klinger (1979) is more involute than either the Canadian or Australian examples, but is similarly compressed. Matsumoto's material (1985, Pl. 5, figs. 5-8) is closest to the Canadian example in degree of whorl overlap, nature of whorl section, and pattern of constrictions. The degree of intergradation and variability present within this group of specimens indicates that the species should not be interpreted according to rigid morphological guidelines, a fact that should be considered in analysis of other species of the genus.

Several other species closely resemble *A. politissimum*. The type material of *A. subtililineatum* (Kossmat, 1895, p. 123, Pl. 19, figs. 1a, 1b, 1c) is known only as small fragments, which show a more rounded and depressed whorl section than *A. politissimum* but a similar degree of involution. The specimen figured by Henderson and McNamara (1985, Pl. 2, figs. 3, 4) is quite similar to the Nanaimo example of *A. politissimum* in its degree of whorl

overlap but shows less frequent and slightly more prorsiradiate constrictions and is slightly more compressed. The specimens figured by Kennedy and Klinger (1979) are too small for comparison. Incidentally, most subsequent workers have incorrectly employed a shortened version, *subtilineatum*, of Kossmat's original spelling of this species' name.

The strongly compressed *Anagaudryceras yokoyamaiforme* Collignon (1969, p. 12, Pl. 516, fig. 2031) from the lower Campanian of Madagascar is also more involute and appears to have more flexuous constrictions, although the photographs are poor and somewhat ambiguous. Likewise, the early whorls of *A. seymouriense* Macellari, 1986 show more flexuous constrictions and a somewhat more involute phragmocone than representatives of *A. politissimum*. The type of *A. mikobokense* Collignon (1956, p. 59, Pl. 8, figs. 1a, 1b, 1c) from the lower Maastrichtian of Madagascar (and also reported from the California lower Maastrichtian; see Matsumoto, 1959b, p. 141) appears to have deeper and wider constrictions than *A. politissimum*, while those on *A. tetragonum* Matsumoto and Kanie, 1985 are weaker and less frequent; those present on *A. matsumotoi* Morozumi, 1985 appear stronger and more rectiradiate. Finally, *A. nanum* Matsumoto, 1985 is also closely allied. This form, known only from a small specimen collected from the lower Campanian of Japan, is almost as evolute as *A. politissimum* but is somewhat more compressed with a steeper umbilical wall. The aspect of frequent subradial furrows and alternating low undulations is similar to the ornamentation noted on the later growth stage of Canadian *A. politissimum*.

Suborder AMMONITINA Hyatt, 1889

Family DESMOCERATIDAE Zittel, 1895

Subfamily DESMOCERATINAE Zittel, 1895

Genus *Desmophyllites* Spath, 1929

Type species. ***Desmoceras Larteti*** Seunes, 1891 as designated by Spath (1929, p. 270).

Remarks. Matsumoto and Obata (1955) provide a generic diagnosis of Spath's genus, which is widespread in the Campanian and Maastrichtian of the Indo-Pacific and tropical regions. ***Desmophyllites diphylloides*** (Forbes) occurs commonly around the Pacific margin and numerous names have been applied to examples found in local areas. Usher (1952) placed Nanaimo specimens within ***Schluteria selwyniana*** (Whiteaves), but Matsumoto (1959b) recognized the identity of much of this material with ***D. diphylloides***. Study of Usher's material, as well as new collections, has shown that several distinct morphologies exist within this group of specimens, and they can be referred to ***D. diphylloides*** and ***D.*** sp. cf. ***larteti*** (Seunes), as well as to several species of ***Damesites***.

Desmophyllites diphylloides (Forbes, 1846)

Plate 8.4, figures 1-13

1846 ***Ammonites diphylloides*** Forbes, p. 105, Pl. 8, figs. 8a, 8b, 8c.

1879 ***Ammonites Selwynianus*** Whiteaves, p. 104, Pl. 13, figs. 1, a.

1952 ***Schluteria selwyniana*** (Whiteaves). Usher, Pl. 5, figs. 3, 4 (only).

1959b ***Desmophyllites diphylloides*** (Forbes). Matsumoto, p. 9, Pl. 13, fig. 3, Textfig. 2 (with synonymy except Usher, 1952).

1970 ***Schluteria selwyniana*** (Whiteaves). Jeletzky (in Muller and Jeletzky), p. 39 (*part.*).

1980 ***Desmophyllites diphylloides*** (Forbes). Blasco de Nullo et al., p. 483, Pl. 2, figs. 9-15.

1984a ***Desmophyllites diphylloides*** (Forbes). Matsumoto, p. 12, Pl. 1, fig. 2.

1985 ***Desmophyllites diphylloides*** (Forbes). Henderson and McNamara, p. 54, Pl. 4, figs. 1-4 (with synonymy).

1985 ***Desmophyllites diphylloides*** (Forbes). Klinger, p. 6, fig. 3D-F, 3L-T.

Lectotype. BM C22682, from the Valudayur beds of Pondicherry, South India, as designated by Matsumoto and Obata, 1955.

Material. Numerous specimens, mostly from Sucia Island. GSC 5803 and 5803a-d, collected by J. Richardson in 1874, mostly complete shells of varying size. GSC 84929 from GSC loc. 16461 includes early whorls; Cedar District Formation, Sucia Island. UW 56356 (UW loc. B-1953), UW 56357 (UW loc. B-1245) and UW 56353 (UW loc. B-1243), are partially preserved adult whorls; all from Cedar District Formation, Sucia Island. UW 56358 (UW loc. B-1245), UW 56352 (UW loc. B-1243), and GSC 90745 (GSC loc. 103849, Cedar District Formation, Sucia Island) are mostly complete individuals retaining much of outer shell layer and ornamentation. An example from GSC loc. 16485, partially crushed, includes only one side of the phragmocone and body chamber, but shows strong constrictions characteristic of the species; upper Cedar District Formation; Saturna Island. UW 56354 (UW loc. B-1246) is partial whorl of intermediate-sized individual; Cedar District Formation, Sucia Island.

Description. Shell very involute, umbilicus narrow and deep with vertical walls and rounded shoulder. Whorl somewhat compressed, reaching greatest width just above mid-flank, with distinctly convergent inner flanks. Venter moderately rounded in immature individuals, but sharply rounded and may show a low but wide swelling in siphonal region of mature individuals.

Outer shell layer exhibits very fine riblets, similar to growth striae, sigmoidal in shape on inner flank, bending sharply forward on outer flank to cross venter. Riblets stronger on inner flank and especially venter, where they form rounded adoral projection. No trace of ornamentation noted on internal mould, although strong and deep constrictions occur there. These are oriented subparallel to surface ornamentation but are straighter across flank and not bent as sharply forward in ventrolateral region, and are shallower and lose prominence crossing the venter.

Dimensions (mm).

Specimen	D	Wb	Wh	Wb/Wh	U(%)
GSC 84929	21.0	8.5*	-	-	1.7(8)
UW 56355	33.2	13.9	18.2	0.76	2.8(8)
UW 56358	47.6	21.9	24.8	0.88	4.6(10)
UW 56356	>52	21.0	29.5	0.71	-

*measurement approximate

Discussion. The specimens are distinct from other Nanaimo desmoceratids in their generally wider whorl section with more broadly rounded venter, the occurrence of weak riblets on the venter forming an adoral projection on juvenile as well as adult forms, and by the occurrence of strongly developed constrictions on all growth stages (Usher, 1952, Pl. 5, figs. 3, 4). Usher (1952) included several forms within his concept of *Schluteria selwyniana* that lack one or more of the above criteria and are better placed in other, closely related species, as discussed below.

Matsumoto (1959b, p. 10) indicated that Californian and Japanese material exhibits about seven constrictions per whorl (presumably full grown individuals) and this is the approximate number of constrictions for most of the mature Nanaimo Group specimens studied. Strong constrictions, five per whorl, are also present at a diameter of 13 mm in the juvenile example from locality GSC loc. 16461.

Usher (1952) reported *Schluteria selwyniana* (Whiteaves) from Saturna Island (GSC loc. 16485), Sucia Island (GSC loc. 65804, lectotype locality), Puntledge River (GSC loc. 15574), Browns River (GSC loc. 15594), and Denman Island (GSC loc. 102252, plesiotype locality). Jeletzky (in Muller and Jeletzky, 1970, Table II) reported *Schluteria selwyniana* as a rare component of the Elongatum, Schmidti, and Vancouverense zones of the Nanaimo Group, but did not list specific localities. The author surveyed the GSC collections of both Usher and Jeletzky, as well as other GSC collections described in Jeletzky's unpublished fossil reports, in an attempt to locate all specimens assigned to the species by these workers. Examples of *Desmophyllites diphylloides* in the GSC collections were only verified from GSC loc. 16485, GSC loc. 65804, and GSC loc. 16461. One of the specimens reported by Usher from GSC loc. 15574 shows the ventral ornamentation characteristic of *Damesites* (described below), the other is too poorly preserved for generic identification. No fragments of desmoceratid ammonites were found in Usher's collections from GSC loc. 15594. However, an unlabelled desmoceratid also referable to *Damesites* was found associated with Usher's collection from GSC loc. 15594, and may be the specimen referred by him to *Schluteria selwyniana.* The additional examples cited by Usher and Jeletzky are herein referred to *Desmophyllites* sp. cf. *larteti* (Seunes), discussed below.

Ward (1976) reported *Desmophyllites diphylloides* from Puntledge River (GSC loc. 102113), Trent River (GSC loc. 102203), Waldron Island (UW loc. A-9990), Sucia Island (UW loc. B-1243, UW loc. B-1245, and UW loc. B-1246), and at Denman Island (GSC loc. 60846). The writer was unable to study the collection from UW loc. A-9990. There are at present no examples of the species in the collections from GSC locs. 102113 and 102203 and the specimen from GSC loc. 60846 is comparable with other Nanaimo examples referred to *Desmophyllites* sp. cf. *larteti* (see below).

All the examples of the species verified by the writer occur in the upper part of the Nanaimo Group sequence. The specimens from Sucia Island all are reported to be from the Cedar District Formation, in the area of Fossil Bay. Strata of the Cedar District exposed on Sucia Island contain the molluscs *Inoceramus* ex gr. *vancouverensis* Shumard, *I. subundatus* Meek, *Hoplitoplacenticeras vancouverense* (Meek), and *Baculites inornatus* Meek, indicative of the lower upper Campanian (Jeletzky, in Muller and Jeletzky, 1970).

The specimen from Saturna Island was collected from the south shore, from strata mapped by Muller (in Muller and Jeletzky, 1970, Fig. 11) as Cedar District Formation. Jeletzky (in Muller and Jeletzky, 1970, p. 70) reported specimens of *Metaplacenticeras* cf. *pacificum* (Smith) collected from lowermost upper Cedar District beds on nearby Denman Island and suggested that upper Cedar District strata in the southeastern Nanaimo basin are probably of *M.* cf. *pacificum* age, late Campanian. Ward (1978a) reported *Baculites rex* Anderson from the Cedar District of Saturna Island, providing additional support for a late Campanian age for these strata.

Ward's reported occurrence of the species on Waldron Island (UW loc. A-9990, unverified by the writer) is from the Pender Formation, Chicoensis Zone, indicating the lower Campanian. *Desmophyllites diphylloides* thus appears to be restricted to strata of Campanian age in British Columbia.

Desmophyllites diphylloides has a circum-Pacific distribution. Blasco de Nullo et al. (1980) report examples from the upper Santonian and lower Campanian of Argentina, similar to its range in South Africa (Klinger, 1985). Henderson and McNamara (1985) record it in lower Maastrichtian beds of Australia, and the species ranges through the Campanian of Japan (Matsumoto and Obata, 1955; Matsumoto, 1984a) and Madagascar (Obata et al., 1981). Matsumoto's (1959b, p. 11, 1960, p. 76) reported California occurrences are all from the Campanian.

Desmophyllites sp. cf. *larteti* (Seunes, 1891)

Plate 8.3, figures 4-8; Figure 8.6

1952 *Schluteria selwyniana* (Whiteaves). Usher, Pl. 6, figs. 1-3, Pl. 31, fig. 20 (only).

cf. 1891 *Desmoceras Larteti* Seunes, p. 19, Pl. 12, fig. 2, Pl. 13, figs. 2, 3.

cf. 1961 *Desmophyllites larteti* (Seunes). Collignon, p. 66, Pl. 26, fig. 2, Textfig. 6.

cf. 1984 *Desmophyllites larteti* (Seunes). Kennedy and Summesberger, p. 156, Pl. 1, fig. 6, Pl. 2, figs. 1-3, 5-6.

Material. GSC 5809b, collected by W. Harvey and hypotype of *Schluteria selwyniana* figured by Usher, a small individual retaining part of the original shell and showing sutures. GSC 5809, collected by W. Harvey, a slightly larger individual, possessing some original shell. Other examples, less well preserved: GSC 84931 (GSC loc. 83909), a slightly crushed and pyritized small individual, possibly referable to the species. GSC 84930 (GSC loc. 60846) includes partially crushed phragmocone with portion of living chamber. An example from GSC loc. 77458 may be identifiable with described material. All specimens from upper Cedar District Formation, Denman Island.

Description. Shell of fairly small to medium size, involute with narrow umbilicus. Whorl section somewhat compressed, reaching greatest width at mid-flank. Flanks subparallel, venter narrowly rounded.

Shell lacks surficial ornamentation. Constrictions on internal mould of phragmocone are very weak and infrequent in occurrence, or absent altogether. Constrictions are better developed on adult body chamber but still weak and infrequent.

Suture of typical desmoceratid form (Fig. 8.6).

Dimensions (mm).

Specimen	D	Wb	Wh	Wb/Wh	U(%)
GSC 84931	17.8	7.2	9.4	0.77	1.9(11)
GSC 5809b	34.3	13.2	18.4	0.72	3.1(9)
GSC 5809	42.7	17.2	22.4	0.77	3.6(8)

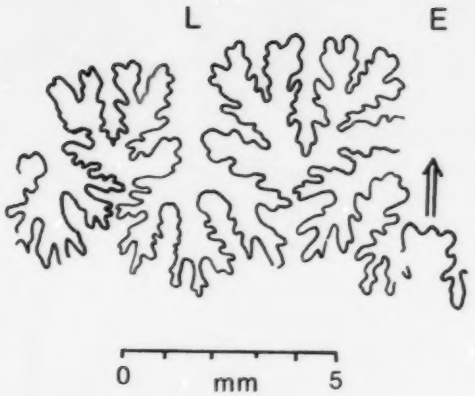

Figure 8.6. *Suture line of* ***Desmophyllites*** *sp. cf.* ***larteti*** *(Seunes), specimen GSC 84930 (GSC loc. 60846), at approximate whorl height = 17 mm.*

Discussion. The specimens resemble those described above as *Desmophyllites diphylloides* but differ in several respects. They are somewhat more compressed with more parallel flanks and a more narrowly rounded venter. The siphonal swelling sometimes noted in mature examples of *D. diphylloides* is not seen at comparable growth stages. Additionally, the prominent, deep and wide constrictions seen on most growth stages of *D. diphylloides* are only weakly developed and infrequent in their occurrence, or lacking altogether, on the examples of *D.* sp. cf. *larteti*. The suture of these forms is similar to that of *D. diphylloides* (Fig. 8.6; Usher, 1952, Pl. 31, fig. 20).

All material was collected from the south and west sides of Denman Island. GSC 5809 and GSC 5809b were assigned by Usher (1952) to GSC loc. 102252, located half a mile south of Village Point, Denman Island. Village Point is no longer indicated on modern maps, but Richardson's map (1878) shows that Village Point is the same as Denman Point, on the west shore of the island, placing the locality within the upper Cedar District Formation. GSC locs. 60846, 77458, and 83909 are also from the Cedar District Formation. Jeletzky (in Muller and Jeletzky, 1970) originally correlated the Cedar District beds on Denman Island with the Vancouverense Zone of the Nanaimo Basin, although they lacked the diagnostic index fossil for the zone. Subsequently, however, he reported specimens of *Metaplacenticeras* cf. *pacificum* collected from the formation (Jeletzky, in Muller and Jeletzky, 1970, p. 70, Addendum 2). Recently, Ward (1978a, p. 420) also correlated the Denman Island section with the upper part of the *Metaplacenticeras* cf. *pacificum* Zone, based on the occurrence of *Baculites rex* Anderson, of late Campanian age. *Desmophyllites* sp. cf. *larteti* thus seems to occur in slightly younger Nanaimo Group strata than *D. diphylloides*.

Genus *Damesites* Matsumoto, 1942

Type species. *Desmoceras Damesi* Jimbo (1894, p. 26, Pl. 1, figs. 2, 2a, 2b, 3), established by Matsumoto (1942, p. 24).

A detailed generic diagnosis for these keeled desmoceratids was provided in Matsumoto, 1954 (p. 266). The genus ranges in age from Cenomanian to Maastrichtian and occurs primarily in the Indo-Pacific region, although examples in the Tethyan region are known from Angola (Howarth, 1968), Romania (Pauliuc, 1968; Szász, 1981), southern Germany (Immel et al., 1981), northern Spain and the Pyrenees (Martinez, 1982; Collignon, 1983), Brazil (Beurlen, 1970), and the western interior of North America (Cobban in Saito and Matsumoto, 1956). Some of these examples are no doubt synonymous with previously described Indo-Pacific species.

Six species have been described from the north Pacific region, occurring more commonly in Japan than in the eastern part of the region. They are *Damesites laticarinatus* Saito and Matsumoto, Cenomanian, Japan; *D. ainuanus* Matsumoto, upper Turonian, Japan; *D. semicostatus* Matsumoto, Coniacian to lower Campanian, Japan; *D. damesi* (Jimbo), including varieties *damesi* and *intermedius*, Coniacian to lower Campanian, Japan and California; *D. sugata* (Forbes), Santonian to Campanian, Japan; and *D. hetonaiensis* Matsumoto, with varieties *hetonaiensis* and *fresnoensis*, Maastrichtian of Japan and California. Distinctions between several of the Cenomanian to Campanian species are subtle, differentiation relying on variations in degree of whorl compression, sharpness and width of keel, presence or absence of lateral keel furrows, and relative strength of lirae and constrictions. In general, older species have a broader keel and more narrowly arched venter than younger ones.

Jeletzky (in Muller and Jeletzky, 1970, Table II) reported *Damesites damesi* var. *intermedius* Matsumoto from both the Elongatum and Schmidti zones of the Nanaimo Group. Ward (1976) also recorded rare examples of the same species at two localities in the Elongatum Zone. P. Ward (pers. comm., 1986) also noted specimens of *Damesites* sp. from Hornby Island, in the upper part of the Nanaimo Group.

Damesites sugata (Forbes, 1846)

Plate 8.4, figures 14-23

1846 *Ammonites Sugata* Forbes, p. 113, Pl. 10, fig. 2.

1955 *Damesites sugata* (Forbes). Matsumoto and Obata, p. 128, Pl. 26, figs. 4a, b, 5a, b, Pl. 27, figs. 3a, b, 4a-d (with synonymy).

1961 *Damesites sugata* (Forbes). Collignon, p. 67, Pl. 27, figs. 1, 1a, 1b, 2, 2a, 2b, Textfig. 7.

1970 *Damesites damesi* var. *intermedius* Matsumoto. Jeletzky (in Muller and Jeletzky), p. 38 and elsewhere.

cf. 1968 *Damesites sugata* (Forbes). Pauliuc, p. 103, Pl. 29, figs. 2, 3.

cf. 1983 *Damesites sugata* (Forbes). Collignon, p. 190, Pl. 2, fig. 4.

Holotype. BM C22674, figured by Forbes (by monotypy).

Material. GSC 84932 (GSC loc. 57182), mould of living chamber of large individual, mildy distorted but with keel and constrictions readily apparent; Nanaimo Group, Forbidden Plateau, (?)Haslam Formation equivalent GSC 84933, a less well preserved, slightly crushed internal mould of living chamber of large individual, also showing keel and constrictions; Haslam Formation, Haslam Creek or Trent River, Elongatum Zone. GSC 84935 (GSC loc. 77405; Haslam Formation, Haslam Creek) and GSC 84938 (GSC loc. 77409; Haslam Formation, Trent River), intermediate sized examples with some altered shell adhering to moulds; both Elongatum Zone. GSC 84934 (GSC loc. 60837; Haslam

Formation, Trent River, Elongatum Zone) and GSC 84937 (GSC loc. 64930; possibly Extension Formation, Northwest Bay), both well preserved, small examples retaining substantial amounts of original shell. GSC 84936 (locality unknown), a very well preserved but small example showing development of constrictions and keel in early growth.

Description. Preserved individuals are fairly small with narrow umbilicus. Whorl section higher than broad, with subparallel or slightly inflated flanks. Specimens with subparallel flanks are generally more compressed, with more abrupt and angular umbilical shoulder and crater-like umbilicus with steep umbilical wall; those with more rounded whorl section show rounded shoulder and less steep umbilical wall. Venter narrowly arched on forms with sharp keel, more rounded on those with less prominent keel.

Ornamentation, when present, consists of radial lirae which form very weak subcostae on outer flank and venter where they are projected strongly forward. Subcostae weaken on approaching mid-venter, leaving smooth and entire keel. Constrictions sinuous and prorsiradiate in early growth stages (to 20 mm diameter), rare in intermediate stages, and prorsiradiate in late stages (above 40 mm diameter). Constrictions most strongly developed on flanks, only weakly pronounced on venter.

Dimensions (mm).

Specimen	D	Wb	Wh	Wb/Wh	U(%)
GSC 84936	15.7	6.7	8.1	0.83	1.7(11)
GSC 84934	26.6	11.5	14.1	0.82	3.2(12)
GSC 84937	31.0	13.3	16.9	0.79	3.8(12)
GSC 84935	-	14.6	19.4	0.75	-

Discussion. Some variability of morphology exists in the Nanaimo Group specimens. Although distinct evidence of growth maturation is lacking in the fossils, there are two distinct size groups, one 30-50 mm in diameter, the other 60-70 mm in diameter. GSC 84932, the largest specimen, is 75 mm in diameter.

A highly variable aspect of the shell is the development of the keel, its width and sharpness as well as the time of its initial development. The two largest specimens, GSC 84933 and GSC 84932, exhibit well defined, narrow and sharp keels on their living chambers. In these specimens, the shell is preserved, including the keel, but it is unknown how strongly the keel is manifested in the internal mould. In GSC 84934, the keel is only weakly developed on the shell layer at a diameter of 21 mm, appearing relatively wide and low. At the same diameter in GSC 84937 the keel is already well developed, although still relatively wider than in the two largest examples, while GSC 84936 shows a strong and sharp keel at a diameter of only 15 mm. In contrast to all these specimens, GSC 84938 exhibits a keel which is only weakly developed in the living chamber at an approximate diameter of 30 mm, appearing low and wide and stronger in the internal mould than in the external shell.

The lirae project strongly forward on the venter, forming a very acute chevron across the siphonal region. This feature distinguishes small specimens lacking a distinct keel from morphologically similar juveniles of *Desmophyllites diphylloides*, which show a much more rounded ventral sinus.

The Nanaimo material is best placed within *Damesites sugata*. The relatively compressed whorl section, prorsiradiate constrictions, lack of ventral keel furrows, and lack of distinct subcostae distinguish the material from *D. damesi* (Jimbo). Morphometric data obtained from the Nanaimo specimens are, in general, more consistent with the allometric relationships determined by Obata (1959) for *Damesites sugata* than for *D. damesi*.

Matsumoto (1954, p. 270) established *Damesites damesi intermedius* for forms intermediate between *D. damesi* (s.s.) and *D. sugata*. The subspecies *intermedius* is more compressed than typical forms of *D. damesi*, with weaker subcostae, a weaker keel, shallower keel furrows, and more prorsiradiate constrictions (Matsumoto and Obata, 1955, p. 131). In several respects, such as weak keel development in some forms, biconvexity of constrictions in the early growth stages, presence of weak subcostae, and variability in degree of whorl compression, some of the Nanaimo specimens closely approach *D. damesi intermedius*, suggesting that the subspecies may be better placed within the synonymy of *D. sugata*, especially as their temporal ranges partially overlap (Matsumoto and Obata, 1955).

The example of *Damesites sugata* figured by Collignon (1983) seems to have a more flattened ventral region and a suggestion of lateral keel furrows.

GSC 84937 was collected from exposures in Northwest Bay, Vancouver Island, mapped as either Comox or Haslam Formation by Muller (in Muller and Jeletzky, 1970, Textfig. 11). However, D. Nunnallee (pers. comm., 1987) informed the writer that the fauna present at Northwest Bay includes *Pachydiscus neevesi* Whiteaves, *Pseudoxybeloceras quadrinodosum* (Jimbo), *Canadoceras yokoyamai* (Jimbo), and *Canadoceras arbucklensis* (Anderson), suggesting a horizon younger than the Elongatum Zone; he thus favours correlation of the Northwest Bay exposures with the Extension Formation of Ward (1978a).

In Japan the species occurs in strata of Santonian age (Matsumoto and Obata, 1955). Collignon (1983) reports possible occurrences in the lower Santonian of the southern Pyrenees. Pauliuc (1968) figured examples from the upper Turonian of Romania, but the illustrations in that report are insufficient for adequate comparison. The species occurs in the lower Coniacian to upper Santonian of Madagascar (Collignon, 1961). Chiplonkar et al. (1985) report occurrences in both the Ariyalur and Trichinopoly groups of South India, of Turonian to Campanian age.

Damesites cf. *sugata* (Forbes, 1846)

Plate 8.5, figures 8, 9

Remarks. The single specimen, GSC 84939, is a poorly preserved fragment of a mould of the living chamber. The fragment is similar to *D. sugata* in its compressed whorl section and strongly projected subcostae on the venter. A faint keel appears to be present on the youngest preserved part of the living chamber. The constrictions preserved on the fragment, however, numbering three per quarter whorl, are much stronger and more numerous than those at a similar growth stage on Nanaimo desmoceratids assigned to *D. sugata*.

The specimen was collected from the Haslam Formation along Puntledge River, GSC loc. 15574, probably the Elongatum Zone.

Family PACHYDISCIDAE Spath, 1922

Genus *Anapachydiscus* Yabe and Shimizu, 1926

Type species. Pachydiscus (Parapachydiscus) fascicostatum Yabe, 1921.

Remarks. The generic diagnosis given by Matsumoto (1951, 1954) is followed here. Numerous species have been assigned to the genus, and they are differentiated by the presence or absence of tubercles and constrictions, and the coarseness, flexuosity, and spacing of the ribs. The shape of the whorl varies, from nearly equidimensional forms such as *Anapachydiscus vistulensis* Błaszkiewicz (1980, p. 49, Pl. 42, figs. 3, 4, Pl. 43, figs. 1, 3, Pl. 48, figs. 1, 2 [T. Matsumoto, pers. comm., 1988, suggests this form may be a species of *Eupachydiscus*]), through all intermediates to strongly depressed species like *A. naumanni* (Yokoyama, 1890, p. 187, Pl. 19, figs. 6, 6a, 6b, Pl. 22, figs. 1, 1a, 1b), *A. sutneri* (Yokoyama, 1890, p. 187, Pl. 23, figs. 1, 1a, 1b), and the material figured here as *Anapachydiscus* sp. nov. aff. *subtililobatus*.

Neopachydiscus Yabe and Shimizu, 1926, established for species with periodic constrictions and accompanying major ribs, is considered a subgenus of *Anapachydiscus* (Matsumoto, 1984a).

Anapachydiscus sp. nov. aff. *subtililobatus* (Jimbo, 1894)

Plate 8.5, figures 1-3

1970 *Pachydiscus* (*Anapachydiscus*) aff. *wittekindi* (Schlüter). Jeletzky (in Muller and Jeletzky), p. 38 and elsewhere.

cf. 1894 *Pachydiscus subtililobatus* Jimbo, p. 176, Pl. 20, figs. 2, 2a, 2b.

Material. GSC 84946 (GSC loc. 16485), a single fragment about one third (120°) of a whorl of phragmocone, with some original shell. The impression of a part of the preceding whorl is also preserved. Cedar District Formation, Saturna Island.

Description. Whorl strongly depressed (Wb/Wh = 1.31), expanding slowly, evenly rounded in circumference, showing no distinct umbilical shoulder. Surface of whorl has evenly spaced, radial ribs, approximately 19 per one third whorl, which bend slightly forward on the outer flank to form broad and shallow ventral sinus. Ribs about half as high as wide, separated by concave interspaces approximately twice as wide as ribs. Adoral face of ribs generally steeper than adapical. Ribbing more strongly defined in outer shell layer than in internal mould. Ribs arise either singly on inner flank or in twos or threes from bundles located at faint and broad bullate swellings inside point of maximum width of whorl. A few ribs arise as intercalations on central to outer part of flank. No constrictions occur in the preserved part of the whorl.

Suture only partly exposed but very deeply incised and elongate, showing considerable degree of overlap by successive septa.

Discussion. The combination of strongly depressed whorl, lack of constrictions, and regularly spaced, moderately strong costae in the Nanaimo specimen differs from all other illustrated Indo-Pacific or European species of *Anapachydiscus* studied by the writer and is thus considered unique to the Canadian taxon. The only other species exhibiting a more depressed whorl section is *Anapachydiscus* (*Neopachydiscus*) *naumanni* (Yokayama). The costae on that species are differentiated into major and minor ribs, more closely spaced, with the ribs projecting slightly more forward on the outer flank. The Canadian form bears greatest resemblance to *A. subtililobatus* (Jimbo, 1894, p. 176, Pl. 20, figs. 2, 2a, 2b), showing a similar frequency and strength of ribbing, but a more depressed whorl section. Both forms lack well developed umbilical tubercles.

Anapachydiscus deccanensis (Stoliczka, 1865, p. 126, Pl. 63, figs. 1, 1a), its subspecies *menabensis* (Collignon, 1955, p. 57, Pl. 18, figs. 3, 3a, 3b, Textfig. 16), and *yezoensis* Matsumoto (1955, p. 179, 1979, Pl. 7, figs. 1, 1a, 1b, 1c, 1d) also exhibit similar cross-sectional views but show pronounced umbilical tubercles. *A. sutneri* (Yokoyama, 1890, p. 187, Pl. 23, figs. 1, 1a, 1b; Matsumoto, 1954, p. 276, Pl. 23, figs. 1a, 1b, 2a, 1b), has less depressed whorls and more numerous, finer ribs. *A. arrialoorensis* (Stoliczka, 1865, p. 126, Pl. 63, figs. 2, 2a, 3, 3a, 4; = *A. arrialoorensis* var. *bererensis* Collignon, 1955, p. 50, Pl. 13, figs. 3, 3a, 3b), *A. peninsularis* (Anderson and Hanna, 1935, p. 20, Pl. 4, fig. 1, Pl. 5, figs. 1, 2, Pl. 6, figs. 3, 4, Pl. 7, fig. 5, Textfig. 1), *A. depressus* (Henderson, 1970, p. 60, Pl. 15, fig. 1), and *A. franciscae* Collignon (1955, p. 53, Pl. 15, figs. 1, 1a, 1b, 2, 2a, 2b, 3, 3a, 3b), Textfig. 13) all show a more equidimensional whorl section and coarser costae, and *Anapachydiscus constrictus* Olivero (1984, p. 81, Pl. 2, fig. 14, Pl. 5, figs. 3, 4, Pl. 6, figs. 1, 2, Textfig. 9) exhibits strong periodic constrictions as well. *Anapachydiscus wittekindi* (Schlüter, 1876, p. 160, with its type *Ammonites robustus* Schlüter, 1872, p. 67, Pl. 21, figs. 1-4, Pl. 22, figs. 1-3; also see Błaszkiewicz, 1980) from northern Europe has a more equidimensional whorl section, which inflates more slowly than that of the Canadian species, and also exhibits more widely spaced, broader, and more rounded ribs with a more pronounced ventral sinus due to their distinct forward bend on the outer flank. The writer considers the Canadian species to be only distantly related to the northern European forms.

The Alaskan species *Anapachydiscus nelchinensis* Jones (1963, p. 44, Pl. 34, Pl. 35, figs. 4, 7-9, Textfig. 23) from the Campanian of the Matanuska Formation has a less depressed whorl section, as well as characteristically weak ornamentation on all growth stages. According to Jones (1963) *A. nelchinensis* occurs in both the zones of *Sphenoceramus schmidti* (Michael) and *Pachydiscus kamishakensis* Jones, spanning most of the Campanian. However, more recent collecting in the Matanuska Formation suggests that occurrences of *A. nelchinensis* in the Kamishakensis Zone may have been misinterpreted (D. Nunnallee, pers. comm., 1987; P.D. Ward, pers. comm., 1987) and the species appears to be restricted to the Schmidti Zone. Ward (1976) reported *Anapachydiscus nelchinensis* Jones in association with *Baculites rex* Anderson from a single locality of the Cedar District Formation on North Pender Island, within the upper part of the cf. Pacificum Zone, uppermost Campanian. The taxonomy and stratigraphy of Nanaimo Group specimens assigned to *A.* cf. *nelchinensis* is given in Haggart and Ward (in press).

Anapachydiscus sp. nov. aff. *subtililobatus* was collected with *Desmophyllites diphylloides* on the south shore of Saturna Island, midway between Croker Point and Taylor Point (J.L. Usher field notebook NS 4748, p. 12). Muller (in Muller and Jeletzky, 1970, Textfig. 11) mapped the south shore of Saturna Island as the lower part of the Cedar District Formation. Other localities of the Cedar District on nearby islands have yielded *Hoplitoplacenticeras vancouverense* (Meek) (Jeletzky, in Muller and Jeletzky, 1970, p. 51); GSC loc. 16485 is thus considered early late Campanian in age.

The type of *Anapachydiscus subtililobatus* comes from the Campanian of Japan (Matsumoto, 1963).

Family MUNIERICERATIDAE Wright, 1952

Genus *Pseudoschloenbachia* Spath, 1921

Type species. *Ammonites Umbulazi* Baily, 1855.

Remarks. The genus includes many diverse forms and is richly represented in Madagascar where Collignon (1969) reports that it makes up 75% of the collected fauna. Collignon recognized several subgenera from the upper Santonian and Campanian; they may ultimately be best treated as individual genera, however. The succession of these subgenera in Madagascar, with over 70 described species, appears to form a lineage, with only *Pseudoschloenbachia (s.s.)* found in the Santonian. Usher (1952) recognized a single species in British Columbia, *P. brannani*, but Jeletzky (in Mulier and Jeletzky, 1970) subsequently identified material comparable to *P. umbulazi* from several localities in the Nanaimo Group. *Pseudoschloenbachia (P.) umbulazi* also occurs in northern California, within the Schmidti Zone (Haggart, 1984a), interpreted as upper Santonian to lowest Campanian.

Subgenus *Pseudoschloenbachia* Spath, 1921

Pseudoschloenbachia (Pseudoschloenbachia) umbulazi (Baily, 1855)

Plate 8.6, figures 1-9; Figure 8.7

1855 *Ammonites Umbulazi* Baily, p. 456, Pl. 11, figs. 4, 4a, 4b, 4c.

1921 *Schloenbachia Umbulazi* (Baily) sp. *forma typica.* van Hoepen, p. 37, Pl. 8, figs. 6-9, Pl. 9, figs. 1, 2.

1921 *Pseudoschloenbachia umbulazi* (Baily). Spath, p. 240, Pl. 20, figs. 2, 3, 3a, Textfig. B 2-7.

1922 *Pseudoschloenbachia umbulazi* (Baily). Spath, p. 139, Pl. 6, fig. 5.

?1952 *Pseudoschloenbachia brannani* Usher, p. 92, Pl. 24, figs. 3, 4, Pl. 31, fig. 25.

1966 *Pseudoschloenbachia (Pseudoschloenbachia) umbulazi* (Baily). Collignon, p. 103, Pl. 499, figs. 1996-1999.

1970 *Pseudoschloenbachia* cf. *umbulazi* Bayle [sic]. Jeletzky (in Muller and Jeletzky), p. 39 (= *Hoplitoplacenticeras* sp.).

1977 *Pseudoschloenbachia (P.) umbulazi sensu lato* (Baily). Klinger and Kennedy, p. 99, figs. 6B-E.

Holotype. The specimen figured by Baily (1855, Pl. 11, fig. 4), BM 5494, by monotypy as noted by Spath (1921, p. 240).

Material. QCIM 3665 (QCIM loc. 224), medium sized, wholly septate, retaining much shell. UW 56359 (UW loc. B-3273), smaller and also completely septate, internal mould with preserved shell only in umbilical region. GSC 90747 (GSC loc. 103851) large specimen, mostly complete GSC 90746 (GSC loc. 103851) partial whorl fragment illustrating both younger and later growth ornamentation; both are wholly septate. All from Haslam Formation near Nanaimo, Schmidti Zone.

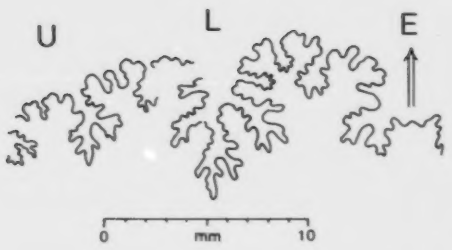

Figure 8.7. *Suture line of* ***Pseudoschloenbachia (P.) umbulazi*** *(Baily), UW 56359 (UW loc. B-3273), at whorl height = 22 mm.*

Description. Shell fairly involute, overlapping previous whorl by two thirds. Whorl compressed, much higher than broad, reaching greatest width just above umbilical shoulder. Umbilicus shallow with steeply sloping wall and abruptly rounded shoulder. Flanks gently convergent toward outer region where they ascend abruptly toward venter. Venter capped by distinctly serrate keel on siphonal line.

Prominent elongate tubercles on umbilical shoulder and at ventrolateral position. Primary rib arises at each umbilical tubercle, bifurcating on inner flank just above tubercle; each bifurcation follows falcoid pattern across flank, weakening on mid-flank, but regaining original strength on outer flank. Each bifurcation terminates at a ventrolateral tubercle, thus there are twice as many ventrolateral as umbilical tubercles. Two fine riblets (perhaps strengthened growth lines) noted on surface of many primary ribs but not in interspaces. Small riblets also occur periodically on venter, forming a deep chevron at each serration of keel.

Suture of smaller individuals shows short and blocky first and second lateral saddles (E/L and L/U), which are asymmetrically tripartite and deeply incised, and asymmetric and tripartite lateral lobes.

Dimensions (mm).

Specimen	D	Wb	Wh	Wb/Wh	U(%)
UW 56359	41.3	11.3	19.2	0.59	7.8(19)
QCIM 3665	66.7	18.0	33.2	0.54	12.9(19)

Discussion. The specimens agree closely with material from South Africa described by Baily (1855), van Hoepen (1921), and Spath (1921, 1922). Specimens of *P. umbulazi* collected from the Schmidti Zone in California led the writer to question the specific uniqueness of *P. brannani* Usher, 1952 (Haggart, 1984b). The early whorls of California specimens identical with *P. umbulazi* (Baily) exhibit a sharp change in ornamentation in the progression to later growth stages. The prominent falcoid ribs on the earlier whorls become reduced, leaving only faint lirae on the otherwise smooth flanks of the outer whorls. Umbilical and ventrolateral tubercles are reduced in strength. Thus, the late growth stage of California *P. umbulazi* is similar to Usher's holotype, and only specimen, of *P. brannani*. Usher's specimen was collected from the Haslam Formation along Brannan (= Benson) Creek, GSC loc. 15658, where it is associated with *Baculites bailyi* Woods and *Sphenoceramus* ex gr. *schmidti* (Michael).

All the figured specimens were collected from the Nanaimo Shale Pit near Nanaimo. The forms *P. umbulazi* and *P. brannani* both occur commonly and in approximately equal numbers at this locality of the Haslam Formation

(D. Nunnallee, pers. comm., 1987). The late Santonian to early Campanian age for this occurrence of *P. umbulazi* on Vancouver Island is thus similar to that observed in California (Haggart, 1984a, b).

In his report, Jeletzky (in Muller and Jeletzky, 1970, p. 39, 50) noted *Pseudoschloenbachia* cf. *umbulazi* in beds of the Cedar District Formation along Trent River, GSC locality 60845. The poorly preserved ammonite moulds in this collection were subsequently identified by Jeletzky as *Hoplitoplacenticeras* cf. *vancouverense* (J. Jeletzky, pers. comm., 1987), although this correction was never noted in publication. The occurrence of *Canadoceras newberryanum* in the same beds at GSC loc. 60845 (Jeletzky in Muller and Jeletzky, 1970, p. 70) further strengthens the correlation of these Cedar District Formation beds on Trent River with the lower upper Campanian. It is thus unlikely that *Pseudoschloenbachia* occurs in these strata, as it is characteristic of the late Santonian to early Campanian.

Suborder ANCYLOCERATINA Wiedmann, 1960

Family NOSTOCERATIDAE Hyatt, 1894

Genus *Eubostrychoceras* Matsumoto, 1967

Type species. *Eubostrychoceras indopacificum* Matsumoto, 1967 by original designation.

Remarks. Differing taxonomic treatments of *Bostrychoceras* Hyatt, 1900 have resulted from the controversy surrounding the definition and limits of its type species *Turrilites polyplocus* Roemer (see Matsumoto 1967, 1977; Kennedy, 1986b). In 1967 (p. 332) Matsumoto proposed the new genus *Eubostrychoceras* for nostoceratids with contiguous or separated, helically coiled whorls in which the aperture of the adult form is in contact with the preceding whorl and faces obliquely upward. Periodic constrictions are normally present throughout growth in these species and the transverse ribs completely lack tubercles. *Bostrychoceras* Hyatt was rigorously excluded from Matsumoto's original concept of *Eubostrychoceras*. In a subsequent discussion of the new genus, Matsumoto (1977, p. 324) elaborated on its morphology, including within it many forms, such as *Heteroceras elongatum* Whiteaves, 1903, in which the adult body chamber forms a large, retroversal hook. Within the expanded definition, several species were included that lack the periodic constrictions during much of ontogeny but have the constrictions at least on the adult body chamber. Matsumoto's emended diagnosis of *Eubostrychoceras* thus included the concept of *Bostrychoceras* Hyatt, 1900, setting aside this name as at least a temporary *nomen dubium* pending redefinition of the Roemer material of *T. polyplocus*.

In an earlier discussion of nostoceratids from California, the author (Haggart, 1984b) elected to follow a more traditional approach and treated *Bostrychoceras* as a subgenus of *Didymoceras*. Most recent workers, however (i.e. Cobban, 1987; Okamoto, 1988; Olivero, 1988) have followed Matsumoto's (1977) proposal in employing the broader concept of *Eubostrychoceras* for *Bostrychoceras* Hyatt, at least until *Turrilites polyplocus* is re-assessed; the author now considers this a more reasonable course.

Eubostrychoceras cf. *japonicum* (Yabe, 1904)

Plate 8.5, figures 4-7

cf. 1904 *Heteroceras* (?) *japonicum* Yabe, p. 17, Pl. 3, fig. 8.

cf. 1904 *Heteroceras* (?) *otsukai* var. *multicostatum* Yabe, p. 16, Pl. 3, fig. 9.

cf. 1977 *Eubostrychoceras japonicum* (Yabe). Matsumoto, p. 329, Pl. 48, figs. 1-4, Pl. 49, figs. 1-3, Pl. 50, figs. 1, 2, Pl. 51, figs. 1, 2, Pl. 52, fig. 3.

Material. GSC 90603 and GSC 90604, body chamber mould fragments, each less than 360° volution; both from GSC loc. 102118, Elkhorn Creek, basal Haslam Formation, Elongatum Zone.

Description. Dextral, open-coiled whorl with elliptical whorl section and rapid translation of whorl along coiling axis. Surface of shell ornamented with numerous simple, moderately strong, narrow and high ribs, rursiradiate on upper part of whorl, parallel to coiling axis in ventral region, prorsiradiate on underside of whorl. Deep constrictions at irregular intervals are most pronounced on outer (ventral) part of whorl and weak or nonexistent on inner (dorsal) part. Latest preserved ribs coarsen, becoming higher and flared.

Early whorls and suture are not preserved.

Discussion. In their gradually enlarging, open helical coil, mostly simple ribs with some flared ones on the latest preserved coils, occasional constrictions, and absence of tubercles, the Nanaimo examples are very similar to *Eubostrychoceras japonicum* from Japan figured by Matsumoto (1977). Matsumoto noted the occurrence of some sinistral specimens but they are less common than the dextral forms. He also noted that the adult body chamber lacks a retroversal hook and gradually deviates from the main coiling axis, resulting in an aperture that faces obliquely upward.

Although the Nanaimo examples appear identical to the Japanese species, the writer is hesitant to consider them conspecific for several reasons. First, Matsumoto (1977, p. 331) states that the Japanese examples are known from the Turonian, although the full range of the species appears to be uncertain. Hirano (1986) also gives an age of lower Middle Turonian. All the Canadian specimens collected so far have been found exclusively in the upper Santonian Elongatum Zone. Second, a large dextrally coiled individual of two and a half whorls, and including the body chamber, was collected by the writer from the upper Santonian along Clover Creek in the Redding area of northern California (in prep.). This locality represents approximately the same stratigraphic level as that of the Nanaimo material. In its mode of coiling and ornamentation the California specimen is nearly identical to the Nanaimo material but it also includes a strongly upturned retroversal hook, similar to that of *Eubostrychoceras elongatum* (Whiteaves, 1903) and in distinct contrast to *E. japonicum*.

The present material differs from the lectotype and other typical examples of *E. elongatum* (Whiteaves, 1903, p. 331, Pl. 44, fig. 2; Usher, 1952, Pl. 28, fig. 3), with which it occurs, in its more open coil with the whorls not in contact, as well as the apparently more frequent constrictions (cf. Usher, 1952, p. 105-106). Smaller, but similar, fragments with this morphology are present in GSC collections from several localities of the Nanaimo Group, all in the Haslam Formation. D. Nunnallee notes (pers. comm., 1988) that the open coiled form is abundant at some localities of the Nanaimo Group, occurring both with and without *E. elongatum* and he favours the open coiled form and typical elongatum to be a dimorphic pair. It is possible that the form represents an extreme degree of polymorphism within *E. elongatum*.

Family DIPLOMOCERATIDAE Spath, 1926

Genus *Ryugasella* Wright and Matsumoto, 1954

Type species. ***Ryugasella ryugasensis*** Wright and Matsumoto, 1954.

Remarks. The generic diagnosis given by Wright and Matsumoto (1954, p. 122) was supplemented by Matsumoto (1959b, p. 169) and revised by Matsumoto and Miyauchi (1984, p. 66). Until recently *Ryugasella* was known only from the north Pacific region with a possible occurrence in Antarctica (Wright and Matsumoto, 1954). Olivero (1988, p. 268, fig. 6) described a second species, *R. antarctica* from the lower Campanian of James Ross Island.

Ryugasella ryugasensis Wright and Matsumoto, 1954

Plate 8.2, figures 12-14

1954 ***Ryugasella ryugasensis*** Wright and Matsumoto, p. 122, Pl. 7, figs. 4, 4a, 4b, 4c, 4d, Textfigs. 7, 13 A-E.

1959b ***Ryugasella ryugasensis*** Wright and Matsumoto. Matsumoto, p. 169, Pl. 37, figs. 4, 4a, 4b, 4c.

1970 ***Ryugasella ryugasensis*** Wright and Matsumoto. Jeletzky (in Muller and Jeletzky), p. 39 and elsewhere.

1984 ***Ryugasella ryugasensis*** Wright and Matsumoto. Matsumoto and Miyauchi, p. 67, Pl. 27, fig. 1.

1987 ***Ryugasella ryugasensis*** Wright and Matsumoto. Mirolyubov, Pl. 25, fig. 8.

Holotype. UMUT MM6583 [= GT I-2862], designated by Wright and Matsumoto (1954, p. 122).

Material. GSC 90638 (GSC loc. 60841; Haslam Formation, Trent River) includes portion of body chamber, retaining some original shell. GSC 90637 (GSC loc. 60842; Haslam Formation, Trent River) and GSC 90610 (unknown locality but definitely Haslam Formation, P. Ward, pers. comm., 1985) both somewhat longer and septate throughout. All specimens from Elongatum Zone.

Description. Shell slightly arcuate, whorl varying from nearly circular to slightly compressed. Annular ribs trend prorsiradiately across flanks and are everywhere of uniform height and thickness on outer shell layer; associated elevations on internal mould are weakened in dorsal region. Ribbing frequency varies from six to eight in a distance along the shaft equal to the whorl height.

Dimensions (mm).

Specimen	L	Wb	Wh	Wb/Wh	RI
GSC 90638	27.4	6.4	6.5	0.98	8
GSC 90610	57.9	6.2	6.8	0.91	6

Discussion. Although the material is fragmentary it is readily identified with the northwestern Pacific species. Matsumoto and Miyauchi (1984) figured an example from the *Sphenoceramus schmidti* Zone of northern Hokkaido. The species is also known from South Sakhalin, U.S.S.R. (Mirolyubov, 1987) (*S. schmidti* Zone *fide* Matsumoto and Miyauchi, 1984, p. 67). Matsumoto (1959b, p. 171) listed occurrences in the upper half of the Chico Formation at Big Chico Creek, northern California, associated with *Submortoniceras chicoense* (Trask) and *Baculites chicoensis* Trask, lower Campanian.

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APPENDIX A

Cited localities of J.L. Usher (1952)

Official Geological Survey of Canada (GSC) locality numbers have subsequently been assigned to the informal designations provided by Usher (1952, p. 46-48), and are given below. Before the list was compiled, Usher's original field numbers and his designated locality numbers (Nos. 10 to 527) were checked against the information in his field notebooks. For several of Usher's original sites (e.g., No. 110, No. 120, etc.) subsequent GSC locality number assignment resulted in two or more lots being derived from the original. Some of these represent in situ occurrences. The collections listed as float occurrences in Usher's notebooks are designated below by an asterisk (*). Detailed locality data can be obtained from the paleontological curator of the GSC, Ottawa.

Usher (1952) Loc. no.	Assigned GSC loc. no.
10	13721
12	13724
14	13725
17	13726
18	13728
19	13729[1]
20	13730
21	13731
23	13719[2]*
104	15556*
107	15561
109	15565*
110	15566, 15567*
111	15568*
112	15569*
113	15570
114	15571
115	15572
118	15574, 15575*, 15578*
120	15576, 15580, 15581*, 15582*, 15583*, 15584
121	15585
122	15586, 15587*
123	15589
124	15590
125	15591
127	13716, 15594[3]
128	15595, 15596*
129	15597
134	15604
135	15605
139	15609
140	15610
141	15611
142	15612, 15613, 15615
143	15614, 15616*, 15617*
144	15618,* 15619
150	15626
151	15627*, 15628
152	15629, 15630*
153	15631
154	15632
155	15634*, 15635
156	15636
157	15637
158	15638
159	15639*
160	15640
161	15641
162	15642
163	15643
164	15644
165	15645
166	15646
167	15647
168	16488
170	16567
200	15649
201	15650*
204	15655*
205	15658*
206	15659, 15660*
208	15662*, 15663*
209	15664
210	15665, 15666*
213	15669
215	15671*
216	15672
222	15676*
224	15679
225	15680
226	15681, 15701
227	15682, 15683*
228	15684
229	15685, 15686*
233	15690
234	15691
236	15693
237	15694
238	15695, 15696*
239	15697
240	15698, 15699*
242	16572
244	16576
245	16582
246	16586
251	16573
252	16475
254	16574
259	16555
260	16477
264	16487
266	16476
268	16485
271	16463, 16473
273	16464
274	16472
275	16474
276	16470
277	16483
281	16471
283	16560
284A	Collection not located
284	16563
285	16559
290	16461
500	102245
501	65810, 77508
502	102246
503	102247
504	102248
505	77512
506	Collection not located
507	Collection not located
508	102249
509	102250
510	77507
511	77501
512	67676
513	102251
514	77500
515	102252
516	102253
517	102910
518	102911
519	77504
520	16482, 77499
521	16480, 16481
522	102912
523	102913
524	102914
525	102915
526	65804
527	Collection not located

[1]Usher's description (1952, p. 46) should read "... at 270° from powerhouse."
[2]According to Usher's notebooks, the actual locality is a float occurrence on the north bank of Brown's River at its junction with Puntledge River.
[3]Locality 13716 collected by A.F. Buckham, 1939.

APPENDIX B

McMaster University Fossil Collections

All Nanaimo Group fossil collections held at McMaster University were transferred to the Geological Survey of Canada collections in Ottawa in October, 1986, with the exception of the ammonites figured in Ward (1978b). Collections from several of the localities discussed by Ward, however, were not located at McMaster University.

McMaster University locality numbers (McM loc.) are given below, followed by assigned Geological Survey of Canada numbers (GSC loc.). Collections not located at McMaster University are not included. Various McMaster localities are now under one GSC locality number, as the original material was not segregated.

McM loc.	GSC loc.	McM. loc.	GSC loc.
100	102121	119	102118
101	102122	120	102117
102	102113	121	102117
103	102113	122	102117
104	102113	123	102117
106	102203	126	102116
107	102119	127	102116
108	102120	128	102115
109	102202	136	102112
110	102119	143	102204
111	102206	147	102205
112	102119	151	102209
113	102111	153	102113
114	102123	157	102114
115	102208	160	102124

APPENDIX C

Fossil localities cited in text

CAS 444 Half a mile west of Henley, Siskiyou County, northern California. Hornbrook Formation, (?)Campanian. Collector: F.M. Anderson.

GSC 7337 East coast of Denman Island, British Columbia. Probably Northumberland Formation, upper Campanian. Collector: J.D. MacKenzie, 1922.

GSC 15556 East shore, Denman Island, British Columbia. Probably Northumberland Formation, upper Campanian. Collector: J.L. Usher, 1945.

GSC 15565 Northwest coast of Hornby Island, British Columbia. Between Shingle Spit and Phipps Point, Spray Formation, uppermost Campanian or lowest Maastrichtian. Collector: J.L. Usher, 1945.

GSC 15574 Puntledge River, British Columbia. Shale bank at powerhouse, Haslam Formation, upper Santonian. Collector: J.L. Usher, 1945.

GSC 15594 Browns River, British Columbia. South bank at mouth, Haslam Formation, upper Santonian. Collector: J.L. Usher, 1945.

GSC 15680 Nanaimo River, British Columbia. South bank opposite lower end of rocky island, Haslam Formation, Santonian. Collector: J.L. Usher, 1945.

GSC 16461 Sucia Island, Washington State. Cedar District Formation in vicinity of Fossil Bay, Vancouverense Zone, lower upper Campanian. Collector: J.L. Usher, 1948.

GSC 16485 South shore of Saturna Island, British Columbia. Upper Cedar District Formation, upper Campanian. Collector: J.L. Usher, 1948.

GSC 16488 Near Arbutus Point, Northwest Bay, Vancouver Island. Haslam or Extension-Protection Formation, upper Santonian to lower Campanian. Collector: J.L. Usher, 1948.

GSC 57182 Forbidden Plateau, Vancouver Island, British Columbia. At elevation 4250 ft (1295 m) on south end of Strata Mountain. Stratigraphic position unknown. Collector: W.J. McMillan, 1963.

GSC 60837 Trent River, Vancouver Island, British Columbia. Base of Haslam Formation, Elongatum Zone, upper Santonian. Collector: J.A. Muller, 1964.

GSC 60841 Trent River, Vancouver Island, British Columbia. Just below Van West logging bridge. Haslam Formation, upper Santonian to lower Campanian. Collector: J.E. Muller, 1964.

GSC 60842 Trent River, Vancouver Island, British Columbia. Downstream from Van West logging bridge. Haslam Formation, upper Santonian to lower Campanian. Collector: J.E. Muller, 1964.

GSC 60845 Trent River, Vancouver Island, British Columbia. Lat. 49°37'13", long. 124°57'50", 0.15 miles (0.2 km) above the powerline over the river. Cedar District Formation, (?) lower upper Campanian. Collector: J.A. Muller, 1964.

GSC 60846 Denman Island, British Columbia. Lat. 49°32'17", long. 124°49'18", 0.3 miles (0.4 km) north of ferry landing on west coast. Cedar District Formation, upper Campanian. Collector: J.A. Muller, 1964.

GSC 64930 Northwest Bay, Vancouver Island. Lat. 49°17'48", long. 124°12'28"W, at Parksville MacMillan Bloedel booming grounds. (?) Comox Formation, Santonian. Collector: J.E. Muller, 1964.

GSC 64939 Haslam Creek, Vancouver Island, British Columbia. Lat. 49°00'28"N, long. 123°59'31"W, junction of Haslam Creek with a tributary. Haslam Formation, Elongatum Zone, upper Santonian. Collector: J.E. Muller, 1964.

GSC 65804 Sucia Island, Washington State. Probably Cedar District Formation, upper Campanian. Collector: J. Richardson, 1874.

GSC 77405 Haslam Creek, Vancouver Island, British Columbia. Haslam Formation, Elongatum Zone, upper Santonian. Collector: J.A. Jeletzky, 1966.

GSC 77409 Haslam Creek, Vancouver Island, British Columbia. Haslam Formation, 8 ft (2.4 m) above contact with Comox Formation, Santonian. Collector: J.A. Jeletzky, 1966.

GSC 77419 Trent River, Vancouver Island, British Columbia. Collected 50 1/2 ft (15 m) above Comox-Haslam Formation contact, Santonian. Collector: J.A. Jeletzky, 1966.

GSC 77458 Denman Island, British Columbia, southwestern shore. Cedar District Formation, upper Campanian. Collector: J.A. Jeletzky, 1966.

GSC 77464 Haslam Creek, Vancouver Island, British Columbia. Benson member of Comox Formation, Santonian. Collector: J.A. Jeletzky, 1966.

GSC 83908 Denman Island, British Columbia. North shore, between (230 to 460 m) 50 and 1500 ft. northeast of point where public road reaches north shore of island. Cedar District Formation, upper Campanian. Collector: J.A. Jeletzky, 1969.

GSC 83909 Denman Island, British Columbia. South shore in the interval 150 to 250 ft (46 to 76 m) southeast of the lighthouse. Cedar District Formation, upper Campanian. Collector: J.A. Jeletzky, 1969.

GSC 87096 Hornby Island, British Columbia. North end of island at Collishaw Point. Upper Spray Formation, lower Maastrichtian. Collector: B. Richards, 1970.

GSC 90888 Shelter Point, Vancouver Island, British Columbia. South of the downtown area of Campbell Bay, Lat. 49°56'30"N, long. 125°10'30"W. Stratigraphic position unknown, upper Campanian. Collector: B. Richards.

GSC 102111 Tsable River, Vancouver Island, British Columbia. Lat. 49°30'50"N, long. 124°52'40"W. Haslam Formation, Elongatum Zone, upper Santonian. Collector: P.D. Ward.

GSC 102113 Puntledge River, Vancouver Island, British Columbia. Shale banks along river from pumping station several hundred metres downstream. Haslam Formation, Elongatum Zone, upper Santonian. Collector: P.D. Ward.

GSC 102114 Bloedel Creek, Vancouver Island, British Columbia. Lat. 49°35'45"N, long. 124°58'45"W. Haslam Formation, Elongatum Zone, upper Santonian. Collector: P.D. Ward.

GSC 102202 Trent River, Vancouver Island, British Columbia. Lat. 49°35'45"N, long. 124°59'15"W. Approximately 200 m downstream of large waterfall. Haslam Formation, Elongatum Zone, upper Santonian. Collector: P.D. Ward.

GSC 102203 Trent River, Vancouver Island, British Columbia. Lat. 49°35'30"N, long. 124°59'20"W. In shales at Van West logging bridge. Haslam Formation, Elongatum Zone, upper Santonian. Collector: P.D. Ward. [= GSC loc. 60839].

GSC 102204 North Pender Island, British Columbia. Lat. 48°45'15"N, long. 123°14'45"W. Shoreline exposure on both sides of Razor Point. Cedar District Formation, cf. Pacificum Zone, upper Campanian. Collector: P.D. Ward.

GSC 102205 South Pender Island, British Columbia. Lat. 48°45'30"N, long. 123°12'10"W, shoreline exposure. Cedar District Formation, cf. Pacificum Zone, upper Campanian. Collector: P.D. Ward.

GSC 102206 Trent River, Vancouver Island, British Columbia. Lat. 49°35'N, long. 124°58'30"W. Approximately 650 ft (200 m) upstream of Bloedel Creek-Trent River intersection. Ganges Formation, Chicoensis Zone, lower Campanian. Collector: P.D. Ward.

GSC 102252 Denman Island, British Columbia. Half a mile south of Village (= Denman) Point. Upper Ceder District Formation, upper Campanian. Collector: W. Harvey, 1896.

MCM 103 Puntledge River, Vancouver Island, British Columbia. Lat. 49°41'05"N, long. 125°01'45"W. In shale banks on river at first major bend downstream of Courtney pumping station. Haslam Formation, Elongatum Zone, upper Santonian. Collector: P.D. Ward.

QCIM 224 Shale Pit, near Nanaimo, Vancouver Island, British Columbia. Haslam Formation, upper Santonian. Collector: D. Nunnallee.

UCLA 3623 Big Chico Creek, California. Section 12, T23N R2E, east bank of creek about 1.25 miles (2 km) south of Mickey's house. Lower part of Chico Formation, Santonian. Collector: L.E. and R.B. Saul, 1952.

UW A-9990 Waldron Island, Washington State. Lat. 48°42'N, long. 123°02'W. In siltstones approximately 80 m above Extension conglomerates, southeast side of island. Pender Formation, Chicoensis Zone, lower Campanian. Collector: P.D. Ward.

UW B-1243 Fossil Bay, Sucia Island, Washington State. Cedar District Formation, Vancouverense Zone, upper Campanian. Collector: D. Nunnallee.

UW B-1245 Fossil Bay, Sucia Island, Washington State. Upper Cedar District Formation, Vancouverense Zone, upper Campanian. Collector: P.D. Ward.

UW B-1246 Sucia Island, Washington State. Lat. 48°45'00"N, long. 122°54'30"W. Halfway between opening and end of Fossil Bay, in shales approximately 200 ft (60 m) stratigraphically above conglomerate. Cedar District Formation, Vancouverense Zone, upper Campanian. Collector: P.D. Ward.

UW B-1953 Fossil Bay, Sucia Island, Washington State. Upper Cedar District Formation, Vancouverense Zone, upper Campanian. Collector: D. Nunnallee.

UW B-1955 Fossil Bay, Sucia Island, Washington State. Upper Cedar District Formation, Vancouverense Zone, upper Campanian. Collector: D. Nunnallee.

UW B-2051 Trent River, Vancouver Island, British Columbia, NTS 92F. Shale exposures above the mouth of Bloedel Creek and below Trent River Falls. Cedar District Formation (= Ganges Formation of Ward, 1976 and Pender Formation of Ward, 1978a), lower Campanian. Collector: P.D. Ward.

UW B-3273 Vancouver Island, British Columbia. Nanaimo Lakes Quadrangle (92F/1 East). Abandoned shale pit approximately 2 miles (3.2 km) southwest of Brannen Lake. Haslam Formation, upper Santonian to lower Campanian. Collector: D. Starr, 1982.

UW B-4802 Trent River, Vancouver Island, British Columbia. Bank of river 500 to 600 ft (150 to 180 m) upstream of GSC loc. 60841. Haslam Formation, Elongatum Zone. Collector: D. Nunnallee.

PLATES 8.1 to 8.6

Figured fossils are designated by the repository abbreviation followed by the assigned specimen type number, e.g. GSC 90603. Accompanying each figure is the locality number, e.g. GSC loc. 102118. Unless stated otherwise, all fossils were coated with ammonium chloride prior to photography and are illustrated at natural size. Unless noted otherwise in caption, arrows indicate position of last identified septum.

PLATE 8.1

Figures 1-3. *Hypophylloceras* (*Neophylloceras*) *surya* (Forbes, 1846)

Lateral view (white arrow indicates umbilical shelf, GSC photo no. 204296), lateral view of opposite flank (GSC photo no. 203690-J), and ventral view of hypotype (GSC photo no. 204299-G), GSC 84918, GSC loc. 87096, upper Spray Formation, Hornby Island.

Figures 4-11. *Saghalinites maclurei* (White, 1889)

4-6. Dorsal, lateral, and ventral views of holotype, USNM 20085 (GSC photo nos. 203807-N, 203807-O and 203807-P, respectively), Sucia Island, probably Cedar District Formation.

7, 8. Dorsal and lateral views of hypotype, GSC 84920 (GSC photo nos. 203689-V and 203689-X), GSC loc. 90888, Shelter Point, Vancouver Island, (?)Northumberland Formation.

9, 10. Dorsal and lateral views of hypotype, GSC 84919 (GSC photo nos. 203685 and 203689-U), GSC loc. 90888, Shelter Point, Vancouver Island, (?)Northumberland Formation.

11. Lateral view of hypotype, UW 56351 (GSC photo no. 204493), UW loc. B-1955, Sucia Island, Cedar District Formation.

Figure 12. *Baculites* sp. cf. *occidentalis* Meek, 1862

Lateral view of GSC 84921 (GSC photo no. 203689-M), GSC loc. 16461, Sucia Island, Cedar District Formation.

Figures 13, 14. *Gaudryceras* aff. *venustum* Matsumoto, 1984

Ventral view, and lateral view of latest part of phragmocone and earliest part of living chamber, GSC 5951 (GSC photo nos. 203690-A and 203690), Sucia Islands, probably Cedar District Formation.

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PLATE 8.2

Figures 1-11. *Gaudryceras striatum* (Jimbo, 1894)

1-4. Lateral and dorsal views, lateral view of opposite flank, and ventral view of hypotype (GSC photo nos. 204289-X, 204293-B, 204292-R and 204293-L, respectively), GSC 84925, GSC loc. 77419, Trent River, lower Haslam Formation.

5-8. Lateral, dorsal, and ventral views, and lateral view of opposite flank of hypotype, GSC 84927 (GSC photo nos. 204290, 204147-Y, 204147-X, and 204290-A, respectively), GSC loc. 102113, Puntledge River, Haslam Formation.

9. Lateral view of GSC 84926 (GSC photo no. 204289-Y), GSC loc. 64939, Haslam Creek, Haslam Formation.

10. Lateral view of GSC 84928 (GSC photo no. 204288-K), GSC loc. 102111, Tsable River, Haslam Formation.

11. Lateral view of hypotype, UW 56367 (GSC photo no. 204496-Q), UW loc. B-4802, Trent River, Haslam Formation.

Figures 12-14. *Ryugasella ryugasensis* Wright and Matsumoto, 1954

12. Ventral view of GSC 90638 (GSC photo no. 204294-4), GSC loc. 60841, Trent River Haslam Formation.

13. Lateral view of GSC 90637 (GSC photo no. 204294-C), GSC loc. 60842, Trent River, Haslam Formation.

14. Lateral view of GSC 90610 (GSC photo no. 203919), unknown locality of Haslam Formation.

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PLATE 8.3

Figure 1. *Gaudryceras denmanense* Whiteaves, 1901

Lateral view of hypotype, GSC 84922 (GSC photo no. 204291-H, specimen uncoated), GSC loc. 7337, east coast of Denman Island, probably Northumberland Formation, x0.5.

Figures 2, 3. *Gaudryceras* aff. *venustum* Matsumoto, 1984

Lateral view of preserved portion of septate inner whorl (x 1.0), and lateral view of a portion of the living chamber (x 0.5), of GSC 10028 (GSC photo nos. 204291-L and 204291-I), GSC loc. 15565, Hornby Island, Spray Formation.

Figures 4-8. *Desmophyllites* sp. cf. *larteti* (Seunes, 1891)

4, 5. Lateral and ventral views of inner whorls. Note compressed whorl section and absence of constrictions. GSC 84930 (GSC photo nos. 204298-N and 204494-A), GSC loc. 60846, Denman Island, upper Cedar District Formation.

6. Lateral view of inner whorls and body chamber fragment showing weakly developed constrictions of GSC 84930 (GSC photo no. 204299-S) (see figures 4, 5).

7, 8. Lateral view showing weakly developed constrictions and ventral view of GSC 5809 (GSC photo nos. 204294-I and 204294-0), Denman Island, upper Cedar District Formation.

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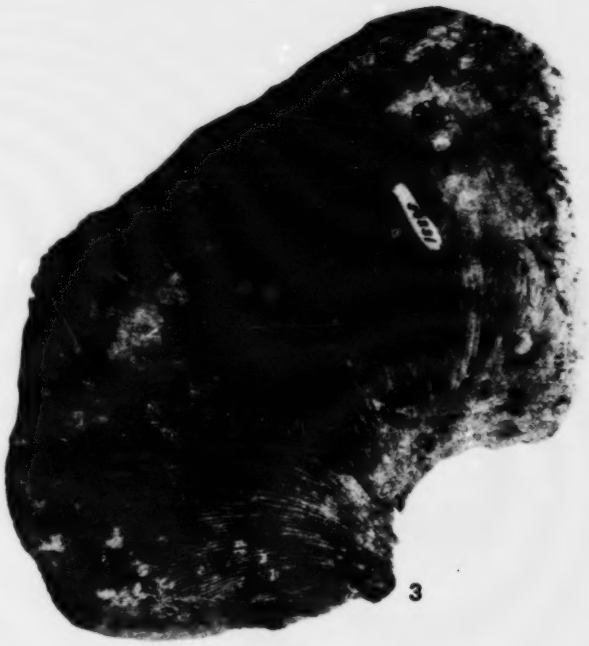
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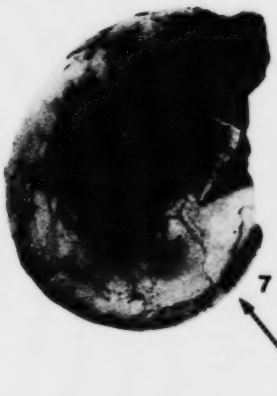
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PLATE 8.4

Figures 1-13. *Desmophyllites diphylloides* (Forbes, 1846)

1. Living chamber of a mature individual preserved as an internal mould. Lateral view displaying four prominent, wide and deep constrictions; no trace of the latest formed constriction is seen on the fragment of outer shell layer which overlies it; the curving pattern of growth striae on the latest preserved part of the living chamber is somewhat more sigmoidal than the trace of the constrictions, UW 56352 (GSC photo no. 204293-Q), UW loc. B-1243, Sucia Island, Cedar District Formation.

2. Ventral view of same specimen as in figure 1. The weak development of siphonal swelling is seen in the upper part of view (GSC photo no. 204295).

3, 4. Lateral view, showing weaker development of constrictions on outer shell layer than on internal mould, and dorsal view, showing widely rounded venter and convergent inner flanks, UW 56354 (GSC photo nos. 204291-E and 204291-F), UW loc. B-1246, Sucia Island, Cedar District Formation.

5, 6. Lateral and ventral views of UW 56355 (GSC photo nos. 204291-C and 204493-S), UW loc. B-1246, Sucia Island, Cedar District Formation, same locality as figure 3.

7. Ventral view displaying prominent siphonal swelling and weak development of constrictions crossing the venter, UW 56353 (GSC photo no. 204298-M), UW loc. B-1243, Sucia Island, Cedar District Formation, same locality as figure 1.

8, 9. Lateral view showing strong development of constrictions on earliest exposed whorls, and ventral view. Note ventral riblets forming the adaperturally oriented sinus in fig. 9. GSC 84929 (GSC photo nos. 204299-X and 204493-Z), GSC loc. 16461 , Sucia Island, Cedar District Formation.

10-13. Lateral and ventral views, lateral view of opposite flank, and dorsal view of GSC 90745 (GSC photo nos. 204496-J, 204496-E, 204496-G, and 294496-O, respectively), GSC loc. 103849, Sucia Island, Cedar District Formation.

Figures 14-23. *Damesites sugata* (Forbes, 1846)

14, 15. Ventral and lateral views of GSC 84937 (GSC photo nos. 204493-E and 204493-A), GSC loc. 64930, Northwest Bay, Vancouver Island, possibly Extension Formation.

16. Ventral view of GSC 84934 (GSC photo no. 204299-R), GSC loc. 60837, Trent River, Haslam Formation.

17. Ventral view of GSC 84938 (GSC photo no. 204298-P), GSC loc. 77409, Trent River, Haslam Formation.

18, 19. Ventral and lateral views of GSC 84935 (GSC photo no. 204494-B and 294493-F), GSC loc. 77405, Haslam Creek, Haslam Formation.

20, 21. Lateral and ventral views of GSC 84932 (GSC photo nos. 204298-L and 204299-E), GSC loc. 57182, Forbidden Plateau, Vancouver Island, (?)Haslam Formation equivalent.

22, 23. Lateral and ventral views of GSC 84933 (GSC photo nos. 204288-J and 204288-E), locality along either Haslam Creek or Trent River, Haslam Formation.

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PLATE 8.5

Figures 1-3. *Anapachydiscus* sp. nov. aff. *subtililobatus* (Jimbo, 1894)

Lateral view of phragmocone fragment (specimen uncoated), and dorsal and ventral views of GSC 84946 (GSC photo nos. 200949-X, 200953-N, and 204298-W, respectively), GSC loc. 16485, Saturna Island, Cedar District Formation.

Figures 4-7. *Eubostrychoceras* cf. *japonicum* (Yabe, 1903)

4, 5. Lateral view of body chamber fragment, and umbilical view from above. GSC 90604 (GSC photo nos. 204539-Q and 204551-B), GSC loc. 102118, Elkhorn Creek, basal Haslam Formation.

6, 7. Lateral view of body chamber fragment, and umbilical view from above. GSC 90603 (GSC photo nos. 204539-I and 204551-A), GSC loc. 102118, same as figure 4.

Figures 8, 9. *Damesites* sp. cf. *sugata* (Forbes, 1846)

Lateral and ventral views of GSC 84939 (GSC photo nos. 204299-W and 204493-Y), GSC loc. 15574, Puntledge River, Haslam Formation.

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PLATE 8.6

Figures 1-9. *Pseudoschloenbachia* (*Pseudoschloenbachia*) *umbulazi* (Baily, 1855)

1, 2. Lateral and ventral views of GSC 90747 (GSC photo nos. 204496-I and 204496-D), GSC loc. 103851, Nanaimo Shale Pit, Vancouver Island, Haslam Formation.

3-5. Lateral and dorsal views, and lateral view of opposite flank of GSC 90746 (GSC photo nos. 204496-K, 204496-N, and 204496-H), GSC loc. 103851, same locality as figure 1.

6. Lateral view of UW 56359 (GSC photo no. 204291-A), UW loc. B-3273, Nanaimo Shale Pit, Vancouver Island, Haslam Formation.

7-9. Ventral, dorsal, and lateral views of QCIM 3665 (GSC photo nos. 204289-D, 204289-G, and 204494-C, respectively), QCIM loc. 224, Nanaimo Shale Pit, Vancouver Island, Haslam Formation.

Figure 10. *Anagaudryceras politissimum* (Kossmat, 1895)

Lateral view of GSC 90743 (GSC photo no. 204496-M), GSC loc. 103852, Hornby Island, upper part of Spray Formation.

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TRICHOPELTINITES COOKSON FROM THE LATEST MAASTRICHTIAN OF CANADA

A.R. Sweet[1] and R.M. Kalgutkar[1]

*Sweet, A.R. and Kalgutkar, R.M., **Trichopeltinites** Cookson from the latest Maastrichtian of Canada. In Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 396, p. 223-227, 1989.*

Abstract

Trichopeltinites, considered indigenous to New Mexico and Colorado during the late Maastrichtian, has been recovered from mudstones immediately below the Cretaceous-Tertiary boundary in north-central Alberta and within late Maastrichtian strata in south-central Saskatchewan. The distribution of *Trichopeltinites* during the late Maastrichtian seems to be correlated with the accumulation of organic material. It is therefore likely that its distribution is controlled by wetness rather than a latitudinal zonation of vegetation.

Résumé

Trichopeltinites, espèce considérée indigène au Nouveau-Mexique et au Colorado durant le Maastrichtien supérieur, a été recueilli dans des pélites (mudstones) situées sous la limite entré le Crétacé et le Tertiaire du centre-nord de l'Alberta et dans des couches du Maastrichtien supérieur du centre-sud de la Saskatchewan. La répartition de *Trichopeltinites* pendant le Maastrichtien supérieur semble être liée à l'accumulation de matières organiques. Sa répartition est par conséquent vraisemblablement contrôlée par l'humidité plutôt que par la zonation latitudinale de la végétation.

INTRODUCTION

Trichopeltinites, an epiphyllous fungal fruiting body, is one of the distinctive components of the late Maastrichtian flora of the Raton Formation in New Mexico and Colorado. Its range is truncated at the Cretaceous-Tertiary boundary (Orth et al., 1981; Pillmore et al., 1984; Tschudy et al., 1984). Although it has been observed in the Lance Formation of Wyoming (Bohor, et al., 1987; D.J. Nichols, pers. comm., 1986), this genus has not previously been recorded from more northerly localities of Maastrichtian age in Montana, Saskatchewan and Alberta, even though the palynofloras from these regions have been extensively documented (Norton and Hall, 1969; Oltz, 1969; Sweet, 1978; Jerzykiewicz and Sweet, 1986a; Nichols et al., 1986; Tschudy and Tschudy, 1986; and Lerbekmo et al., 1987). Hence, the presence of *Trichopeltinites* appears to represent one of the latitudinally imposed floristic differences that existed within the midcontinental region of North America during the late Maastrichtian.

Trichopeltinites has also been recorded from the Tertiary of Australia (Cookson, 1947), the Eocene of western Tennessee (Dilcher, 1965) and the Miocene of India (Ramanujan, 1982; Rao and Ramanujam, 1976). These records imply that the disappearance of *Trichopeltinites* from the stratigraphic record in the southern midcontinental region at the end of the Maastrichtian was a regional, rather than a universal, extinction of this taxa.

The purpose of this paper is 1) to document late Maastrichtian occurrences of *Trichopeltinites* from the Wabamun area of north-central Alberta and the Morgan Creek east locality of south-central Saskatchewan, and 2) to suggest possible paleoenvironmental reasons for its disjunctive geographic distribution (Fig. 9.1).

MATERIAL

Sixty dispersed and fragmented stromata of *Trichopeltinites* sp. were observed in a sample of core from the Transalta Utilities C-HV-83-07 borehole (Fig. 9.1) located near the Highvale Coal Mine Pit 3 on the south side of Wabamun Lake (GSC loc. C-135400; sec. 35, tp. 52, rge. 5, W. 5th mer.); sample from an interval 47.29 to 47.44 m below surface, or 0.07 to 0.22 m below No. 6 coal seam; lower Scollard Formation. Additional poorly preserved specimens were recovered from a core sample of greenish grey mudstone from the 49.095 to 49.145 m interval of the Transalta Utilities WW86-911 borehole located within the Whitewood mine area north of Wabamun Lake (GSC loc. C-137597; sec. 30, tp. 53, rge. 4, W. 5th mer.). At both of these north-central Alberta localities, the samples containing *Trichopeltinites* sp. were from immediately below the Cretaceous-Tertiary boundary, which can be placed palynologically at the base of a major coal-bearing interval or, in local terminology, the No. 6 coal seam (Fig. 9.1). In both cores, thin coal seams and carbonaceous mudstone occur within a five metre interval beneath the Cretaceous-Tertiary boundary.

Specimens of *Trichopeltinites* were also found in samples from the Morgan Creek east outcrop locality in south-central Saskatchewan (LSD 6, sec. 18, tp. 1, rge. 4, W. 3rd mer.), located on the west-facing valley wall, approximately 2.5 km (1.5 miles) east of the Morgan Creek locality of Nichols et al. (1986). *Trichopeltinites* occurs in the Frenchman Formation 20.2 to 20.7 m below the Cretaceous-Tertiary boundary in two contiguous samples, the lower from a 0.3 m thick, reddish brown, coaly shale, and the upper from a 0.2 m thick, light grey mudstone with root casts in its lower part. A 0.2 m thick coal seam occurs 0.6 m lower in the section.

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Most *Trichopeltinites* specimens were found as fragments in the samples. Stromatic tissues from the Transalta Utilities boreholes were mainly detached fragments devoid of fruiting bodies. However, fertile stromatic fragments were found subtending ascomata in the sample from Morgan Creek. The ascomata occur as round, thickened, dark structures located within the fragmented detached lobes, either singly (Pl. 9.1, fig. 4) or in small clusters (Pl. 9.1, figs. 5, 6). The following description is based on 12 incomplete specimens from the Transalta Utilities C-HV-83-07 borehole, and 16 from the Morgan Creek east locality.

SYSTEMATIC DESCRIPTIONS

Order MICROTHYRIALES

Family MICROTHYRIACEAE

Subfamily TRICHOPELTEAE

Genus *Trichopeltinites* Cookson, 1947

Trichopeltinites sp.

Plate 9.1, figures 1-6

Description. Stromatic parts linear, one layer of cells thick, irregularly ribbon shaped, narrowly elongate with evenly lobed margins appearing somewhat leaf-like in form. Stromatic tissues flattened, brown, formed by closely adpressed, laterally united hyphae. Stromatic cells elongated toward periphery, forming thickened marginal lobes of varying size, and shape. Stromatic fragments variable in size, (largest measured length, 225 µm; greatest width, 117.5 µm) specimens from the Morgan Creek locality.

Remarks. Two species of fossil *Trichopeltinites* have been documented. Cookson (1947) described *T. pulcher* from Tertiary deposits in the southern hemisphere, and Dilcher (1965) named *T. fusilis* from Eocene deposits in western Tennessee, U.S.A. The stromata of these species appear morphologically similar, but differ primarily in the size of their ascomata: *Trichopeltinites fusilis* has smaller ascomata than those of *T. pulcher*. Rao and Ramanujam (1976) found specimens of *Trichopeltinites* in the Neogene deposits of Kerala in southern India that differed from *T. fusilis* in being larger and more robust with prominently thick-walled cells. These may represent a third, as yet unnamed, species.

As in *T. pulcher*, the ascomata in the Morgan Creek material have mature fruiting bodies with openings formed by irregular fissures (Pl. 9.1, figs. 5, 6). However, the ascomata on the detached fragments of *Trichopeltinites* from the Morgan Creek locality appear to be generally larger in size (42 to 250 µm in diameter) than those of either *T. fusilis* (25 to 30 µm in diameter) or *T. pulcher* (72 to 90 µm in diameter). The large range in size recorded for ascomata in this study makes the taxonomic significance of this characteristic uncertain. Hence, until more ascomata have been found and their size range determined, the appropriateness of assigning the late Maastrichtian specimens to *T. pulcher* or, alternatively, to a new species is left unresolved.

DISCUSSION

Coal occurs in the upper, late Maastrichtian part of the Raton Formation (Pillmore et al., 1984). Similarly, thin beds of coal and carbonaceous mudstone occur in the late Maastrichtian of north-central Alberta (Fig. 9.1), and carbonaceous mudstone and coal occur below the Cretaceous-Tertiary boundary at the Morgan Creek east locality. Specimens of *Trichopeltinites* were recovered from the interval between the thin coal and carbonaceous mudstone and the Cretaceous-Tertiary boundary, immediately below the main coal-bearing interval in north-central Alberta (Fig. 9.1). In south-central Saskatchewan, *Trichopeltinites* specimens were recovered from a coaly shale and the immediately overlying mudstone, as outlined previously. Although the accumulation of organic matter was not as extensive in the late Maastrichtian of north-central Alberta and south-central Saskatchewan as in the Raton Formation, the common presence of accumulated organic matter suggests a correlation between the wetness of the environment and the occurrences of *Trichopeltinites*.

At other Cretaceous-Tertiary boundary sections in Alberta, namely the central Foothills (Jerzykiewicz and Sweet, 1986a), the Red Deer Valley of the central plains region (Sweet and Hills, 1984; Lerbekmo et al., 1987) and the southern foothills belt (Jerzykiewicz and Sweet, 1986b), no specimens of *Trichopeltinites* have been observed. Likewise, none has been reported from the Frenchman Formation of southwestern Saskatchewan (Sweet, 1978; Lerbekmo et al., 1987), and the Hell Creek Formation of Montana (Norton and Hall, 1969; Oltz, 1969; Tschudy and Tschudy, 1986). There have been no reports of coal in the interval immediately preceding the Cretaceous-Tertiary boundary at any of the above localities. In addition, these localities are marginal to the semiarid region present during the late Maastrichtian in southwestern Alberta and northwestern Montana, as indicated by the presence of abundant caliche in the Willow Creek Formation (Jerzykiewicz and Sweet, 1986b).

The living members of microthyriaceous fungi, to which *Trichopeltinites* is most closely allied, are generally found in tropical, subtropical, or warm temperate zones associated with vegetation preferring high humidity (Cookson, 1947; Dilcher, 1965; Venkatachala and Kar, 1969; Kar and Saxena, 1976; Ramanujam, 1982). Tertiary occurrences of *Trichopeltinites* are from strata interpreted as having been deposited under conditions of high humdity (Cookson, 1947; Dilcher, 1965; Ramanujam, 1982). Hence, the presence of both *Trichopeltinites* and coal in the late Maastrichtian of the Raton basin, north-central Alberta and south-central Saskatchewan, suggests a relatively wet environment in these areas immediately preceding the Tertiary. This interpretation is supported by the absence of *Trichopeltinites* from semiarid and contiguous areas during the late Maastrichtian.

Two conclusions can be derived from the above distribution of *Trichopeltinites* and its association with coal-bearing facies in the late Maastrichtian: 1) the presence of *Trichopeltinites* is probably a reliable indicator of a high level of moisture in the environment of deposition, and 2) it is apparent that factors other than those imposed by latitude affected the distribution of vegetation within the midcontinental region of North America during the late Maastrichtian. Floristic models, used to demonstrate the magnitude of change at the Cretaceous-Tertiary boundary, based on the latitudinal zonation of vegetation (see Wolfe and Upchurch, 1986) do not take into account these regional differences in the environment of deposition. Therefore, the magnitude of change implied by these models may be open to question.

ACKNOWLEDGMENTS

We acknowledge the helpful critical review of the manuscript by B.S. Norford and D.J. McIntyre and the help of J. Elberg in compiling Figure 9.1. The presence of *Trichopeltinites* in the samples from south-central Saskatchewan was pointed out to us by D. Braman.

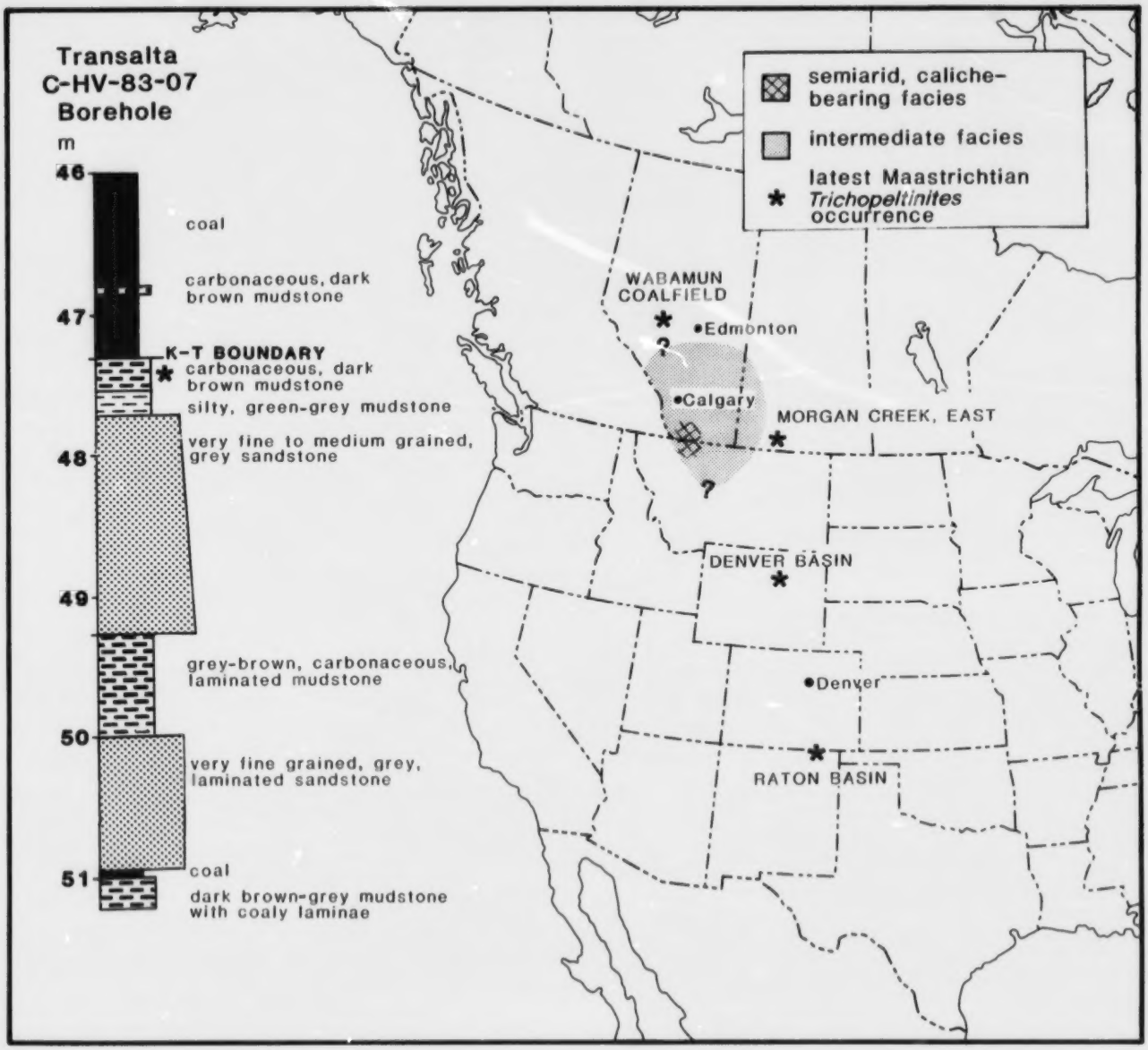

Figure 9.1. Occurrences of ***Trichopeltinites*** *in the late Maastrichtian of North America and the stratigraphic position of the new occurrence in north-central Alberta.*

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PLATE 9.1

Figures 1-6. *Trichopeltinites* sp.

Figures 1, 3. C-135400, Transalta C-HV-83-07 borehole. Stromatic tissue showing undulating and thickened margin.

1. 0.12-0.22 m, P2844-20a, 119.8 x 15.3, GSC 91328, x750.

3. C-135400, 0.07-0.12 m; P2844-19a, 114.3 x 15.0; GSC 91330; x750.

Figures 2, 4-6. C-145894, Morgan Creek, east locality.

2. Stromatic tissue, P2940-3f, 125.4 x 5.1, GSC 91329, x400.
4. Ascoma attached to stromatic tissue, P2940-3f, 109.5 x 13.3, GSC 91331, x300.

5, 6. SEM micrographs of ascomata with irregular fissures attached to stromatic tissue with cellular projections from the surface, P2940-3i, remounted from SEM stub, GSC 91332, x100 and GSC 91333, x75 respectively.

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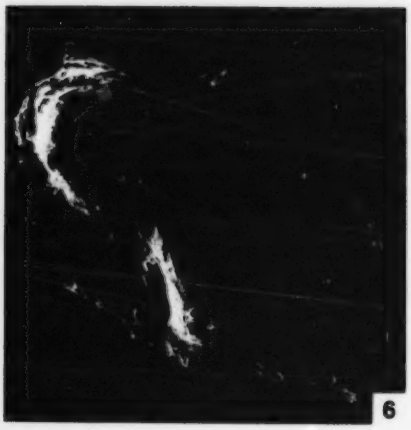

6

NEOGENE FORAMINIFERAL BIOSTRATIGRAPHY OF THE SOUTHERN QUEEN CHARLOTTE BASIN

R. Timothy Patterson[1]

Patterson, R.T., Neogene foraminiferal biostratigraphy of the southern Queen Charlotte Basin. In Contributions to Canadian Paleontology, Geological Survey of Canada, Bulletin 396, p. 229-265, 1989.

Abstract

Forty-two species of benthic and planktonic Foraminifera were identified in 296 samples from the Shell Anglo Murrelet L-15, Harlequin D-86, and Osprey D-36 wells of the Queen Charlotte Basin. Two distinct temporal and four distinct depositional environments are recognizable. Interpretations are, however, limited by major zones of faunal nonrecovery, and sparse foraminiferal data.

In the upper parts of the Harlequin D-86 and Osprey D-36 wells, a well developed, essentially modern boreal benthic foraminiferal community was identified. Because all species found in this zone range from at least the Pliocene and are extant, biostratigraphic resolution finer than the Pliocene-Quaternary is not possible.

Seismic data indicate that the upper and lower faunal zones identified in all three wells are separated by regional unconformities that occurred in the Late Miocene and Pliocene.

The presence of characteristic neritic fauna and, in Murrelet L-15, three coal seams, indicate alternating shallow marine and nonmarine conditions during deposition. The sediments in the lower parts of the wells were probably deposited no later than middle Miocene (Luisian Stage).

The Miocene foraminifers from the Harlequin D-86 and Murrelet L-15 wells are extensively diagenetically altered. This suggests an increase in thermal and geochemical maturity northward in the Basin.

Résumé

Quarante-deux espèces de foraminifères benthiques et planctoniques ont été relevées dans 296 échantillons provenant des puits Shell Anglo Murrelet L-15, Harlequin D-86 et Osprey D-36 dans le bassin de la Reine-Charlotte. Deux milieux temporels distincts et quatre milieux de sédimentation distincts sont identifiables. Cependant, l'interprétation est limitée par l'absence de faune dans d'importantes zones et par une pénurie de données ayant trait aux foraminifères.

Dans la partie supérieure des puits Harlequin D-86 et Osprey D-36, on a identifié la présence d'une communauté de foraminifères benthiques de nature boréale bien développée et essentiellement contemporaine. Comme toutes les espèces trouvées dans cette zone remontent au moins jusqu'au Pliocène et qu'elles existent encore, une résolution biostratigraphique plus subtile permettant de les situer à une époque plus exacte que le Pliocène et le Quaternaire n'est pas possible.

Des données sismiques indiquent que les parties supérieure et inférieure des zones fauniques relevées dans les trois puits sont séparées par des discordances régionales datant du Miocène supérieur et du Pliocène.

La présence d'une faune néritique typique et, dans le puits Murrelet L-15, de trois couches de charbon, indique que des conditions alternantes de milieux marin peu profond et non marin régnaient pendant leur accumulation. Les sédiments des parties inférieures des puits ont probablement été mis en place après le Miocène moyen (étage luisien).

Les foraminifères miocènes des puits Harlequin D-86 et Murrelet L-15 sont diagénétiquement très altérés, phénomène qui laisse supposer une augmentation de la maturité thermique et géochimique vers le nord du bassin.

INTRODUCTION

During the 1960s several onshore and offshore exploration wells were drilled across the Queen Charlotte Basin to determine the hydrocarbon potential of the region. After an almost 20 year hiatus in exploration activity in the Queen Charlotte Basin, there is renewed interest in the area. The purpose of this study is to analyze quantitatively the benthic and planktonic foraminiferal fauna found in three wells (Fig. 10.1), Murrelet L-15, Harlequin D-86, and Osprey D-36, located in the southern part of the basin, and to provide a biostratigraphic and paleo-oceanographic interpretation of the resultant data. It is also the purpose of this study to illustrate fully the foraminiferal fauna using scanning electron micrographs, and to upgrade the systematic descriptions of the various taxa, thus providing a database for future study and exploration of the basin.

GEOLOGICAL HISTORY OF THE QUEEN CHARLOTTE BASIN

The Tertiary deposits of the Queen Charlotte Basin lie west of the Coast Range Batholith as far as the Queen Charlotte Fault, beneath modern Hecate Strait and Queen Charlotte Sound (Fig. 10.1). Pre-Neogene outcrops on the Queen Charlotte Islands comprise over 9000 m of Mesozoic and lower Tertiary sedimentary, metamorphic, igneous, and volcanic rocks. Cameron and Hamilton (1988), have determined that the oldest depositional unit in the basin is composed of volcanic rocks of the Triassic Karmutsen Formation. So far, fully marine units have been found only in wells from the southern part of the basin. The deposits from these wells date from the early Miocene. The Miocene deposits of the Queen Charlotte Basin range from nonmarine mudstone, sandstone, lignite, and pebble conglomerate in the north, to marine sandstone, siltstone, and shale in the south, and are known as the Skonun Formation (Sutherland Brown, 1968).

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From seismic mapping it can be seen that deposition in the southern area of the basin occurred over volcanic terrain of varied relief (Shouldice, 1971). In general, deposition to the north of the Murrelet L-15 well was nonmarine to very shallow marine, while deposition at the sites of the Harlequin D-86 and Osprey D-36 wells was mostly deeper marine. Murrelet L-15 is at the boundary of the marine/nonmarine facies; the base of the well is marine, with a few nonmarine intervals, followed by a thick upper Miocene – Pliocene nonmarine unit, in turn overlain by a Pliocene – Quaternary marine unit. Shouldice (1971) interpreted this lithology as indicating an initial transgression in the Miocene that flooded the various topographic lows and was then followed by a minor late Miocene regression, as seen from the nonmarine units found at the Murrelet L-15 site. The foraminiferal evidence from the present study indicates that a second transgression occurred in the Pliocene. Two regional unconformities, spanning parts of the late Miocene and early Pliocene, have been recognized from seismic profiles (Shouldice, 1971).

Due to structural and lithological complexities in the region, a correlation between the Murrelet L-15, Harlequin D-86, and Osprey D-36 wells is not possible using mechanical logs or lithotypes. Such an analysis is possible only through the interpretation of seismic, palynological, or foraminiferal data (Shouldice, 1971).

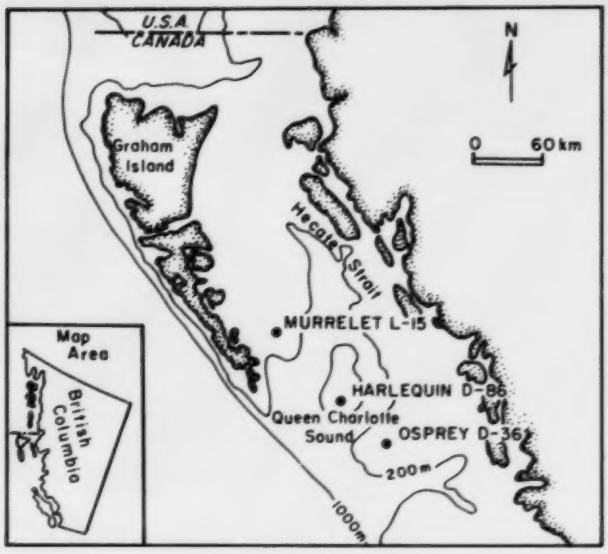


Figure 10.1. *Location map, Queen Charlotte Basin.*

LITHOLOGY AND DRILLING HISTORY

Shell Anglo Murrelet L-15

Shell Anglo Murrelet L-15, drilled as part of Shell Canada's west coast offshore exploratory program, was sited 32 km east of Scudder Point, Queen Charlotte Islands (Fig. 10.1) in 111 m of water. The well history report did not state the purpose of drilling the well. However, as with Shell Canada's other wells in the basin, Murrelet L-15 was most likely drilled as a stratigraphic test. The well was spudded on April 11, 1969 and abandoned on May 4, 1969, at a total depth (T.D.) of 2919 m.

Conventional open-hole logs and sidewall samples were obtained prior to placing intermediate casing in the well. This casing was set to a depth of 1066 m. The lithology from the surface to a depth of 1164 m consists primarily of sandstone (≈90%) interspersed with a few silt, clay, mud, and shale beds. This section is situated at the top of a micropaleontological sampling gap. This lithology continues through the hiatus. The frequency and thickness of the silt, clay, mud, and shale beds increase below the hiatus, an interval from 2006 to 2545 m, although sandstone still constitutes more than 50 per cent of the section (Fig. 10.2).

Below the 2545 m level of the well, a dramatic shift in lithology occurs. From 2545 m to 2825 m, the proportion of sandstone becomes even more reduced, and three coal seams, at 2545, 2717, and 2821 m, respectively, were found in the well. The base of the section, from 2826 m to T.D., is composed primarily of detrital volcanic material and a few thin shale beds (Fig. 10.2).

Shell Anglo Harlequin D-86

Shell Anglo Harlequin D-86, also drilled as part of Shell Canada's west coast offshore exploratory program, was drilled approximately 74 km due east of Cape St. James, Queen Charlotte Islands (Fig. 10.1) in 140 m of water. The purpose of the well was to perform a stratigraphic test of the basin without reference to any particular geological structure. The well was spudded on September 22, 1968 and plugged and abandoned on October 15, 1968 at a total depth of 3241 m.

As with Murrelet L-15, conventional openhole logs and sidewall samples were obtained prior to setting intermediate casing to a depth of 1100 m. In addition, two conventional cores were cut from 1352 to 1359 m and 1676 to 1684 m to determine the reservoir characteristics of the formation. Caliper logs showed notable caving at several intervals in the well at the following depths: 314 to 610 m; 701 to 914 m; 1253 to 1308 m; 1463 to 1527 m; 1622 to 1859 m; 1957 to 2018 m; 2067 to 2271 m; 2286 to 2384 m (minor); 2411 to 2954 m (minor); and 3127 to 3170 m.

The rock types of Harlequin D-86 are generally uniform until near the base of the well. From 384 to 1734 m, there is approximately 30 per cent siltstone and 10 per cent shale, and the remainder is sandstone. From 1734 to 1807 m, there is a sampling hiatus. However, the sonic and gamma logs suggest that there is little change in lithology. From 1807 to 3018 m, the rock types are similar to those found in the upper part of the core. From 3018 to 3149 m there is approximately 80 per cent siltstone, and approximately 10 per cent each of sandstone and shale. In addition, there are approximately three metres of volcanics between 3135 and 3138 m. From 3149 m to the total depth of 3241 m, the lithology changes radically and consists of igneous, volcanic and tuffaceous intervals with a few interbedded shales (Fig. 10.3).

Shell Anglo Osprey D-36

Shell Anglo Osprey D-36, a third well drilled as part of Shell Canada's west coast offshore exploratory program, was drilled approximately 97 km northwest of Cape Scott, Vancouver Island (Fig. 10.1) in 59 m of water. The purpose of the well was to conduct a stratigraphic test of the basin without reference to any particular structure. The well was spudded on September 10, 1968 and was plugged and abandoned on September 16, 1968 at a total depth of 2530 m.

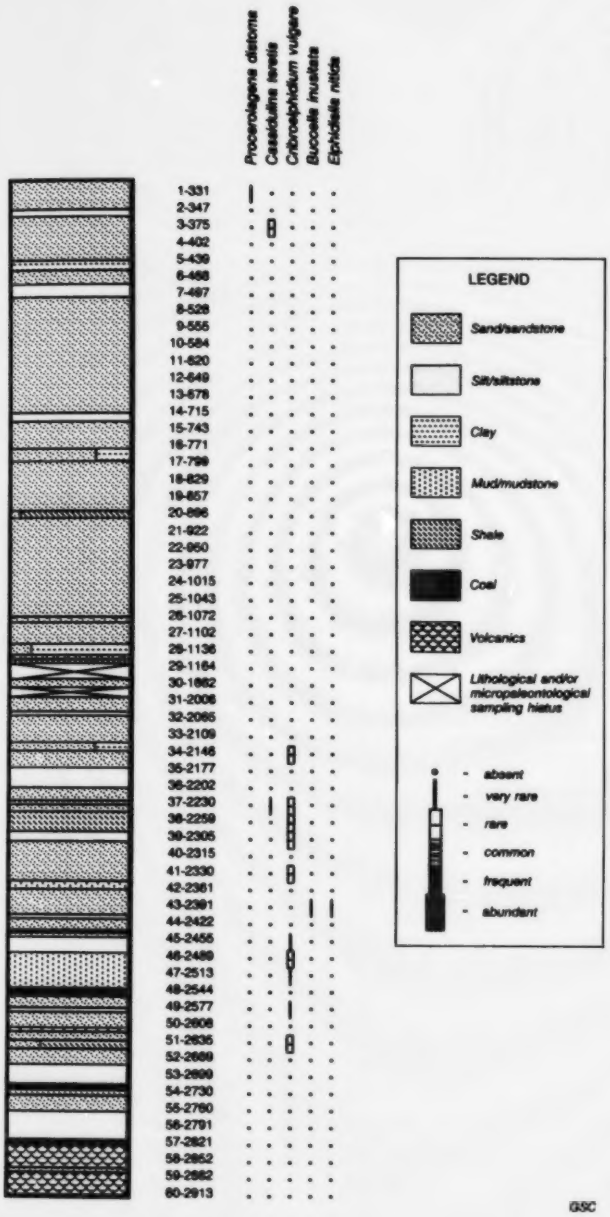


Figure 10.2. *Semiquantitative frequency distribution of benthic Foraminifera from the Murrelet L-15 well in the Queen Charlotte Basin. Lithology summarized from Shell Canada Ltd. well history report.*

As for Murrelet L-15 and Harlequin D-86, conventional openhole logs and sidewall samples were obtained prior to placing intermediate casing in the well to a depth of 1056 m. A six-metre conventional core was cut at 1754 m for stratigraphic control. The caliper logs indicate that there was considerable downhole caving in Osprey D-36 at the following depths: several short intervals between 210 to 655 m; 731 to 747 m; below the last casing from 1074 to 1219 m; 1234 to 1250 m; 1387 to 1524 m (minor); and 1920 to 1966 m.

In the Osprey D-36 well, a foraminiferal sampling gap occurs from 1037 to 1688 m. The rock types above this gap are alternating units of mudstone (33%), sandstone (24%), shale (19%), and siltstone (18%), with mudstones more prevalent near the top of the interval, and shales more common near the base. The rock types below the sampling gap, from 1688 to 1886 m, are similar to those found in the upper part of the core. However, the lithology from 1886 m to the base of the well – 2529 m – changes dramatically. This lower interval is dominated by thick volcanic units, interspersed with thinner sandstone and siltstone units. In the volcanic units the gamma log values drop and the sonic velocities increase. However, the sonic values are highly irregular, and commonly drop toward the sonic values of the sediments. This most likely indicates that the volcanics consist of flows interspersed with volcanically derived sediments – possibly pyroclasts, reworked pyroclastics, or eroded basalts (J. White, pers. comm., 1988). Of particular interest in the lower interval is the coal-bearing sandstone found between 2347 m and 2362 m. The existence of coal here indicates that this unit probably was deposited under continental, rather than marine, conditions (Fig. 10.4).

MATERIAL AND METHODS

The foraminifers on previously picked slides obtained from three wells drilled in the Queen Charlotte Basin were identified. The wells and intervals examined were: Murrelet L-15, 330 to 2914 m (60 slides); Harlequin D-86, 385 to 3237 m (94 slides); and Osprey D-36, 296 to 2530 m (142 slides). The stratigraphic positions of these samples were originally recorded in feet, and those measurements are inscribed on the picked slides. To avoid confusion, Appendices 1 to 3 provide a cross-reference between the metric units used herein and the original Imperial units.

Taxa were semiquantitatively tallied using a Wild-Heerbrugg M-8 stereoscopic dissecting microscope. The following classification was used: a single occurrence of a species in a sample: very rare; two to four occurrences: rare; five to nine occurrences: common; ten to fifteen occurrences: frequent; more than fifteen occurrences: abundant (Figs. 10.2-10.4). The biostratigraphic ranges and relative frequency of each additional species were plotted using the Checklist II program on an IBM-XT personal computer. Additional figures were prepared using various drafting programs on a Macintosh SE personal computer. All taxa were illustrated using an ISI Super-III scanning electron microscope with Polaroid P/N 55 positive-negative film.

RESULTS

Murrelet L-15

Faunal analysis of Murrelet L-15, the most northerly of the three wells in the Queen Charlotte Basin, is based on 60 previously picked slides obtained from the 330 to 2911 m levels of the well. Only 13 of the 60 samples yielded identifiable taxa (Fig. 10.2).

The fauna from Murrelet L-15 can be grouped into two identifiable clusters, found in strata separated by a long interval of nonmarine sandstone and shale. A single occurrence of *Procerolagena distoma* (Parker and Jones), 1864 in sample 1 (330-337 m), and a rare occurrence of the long-ranging *Cassidulina teretis* Tappan, 1951 in sample 3 (374-383 m) are the only taxa found in the upper faunal zone.

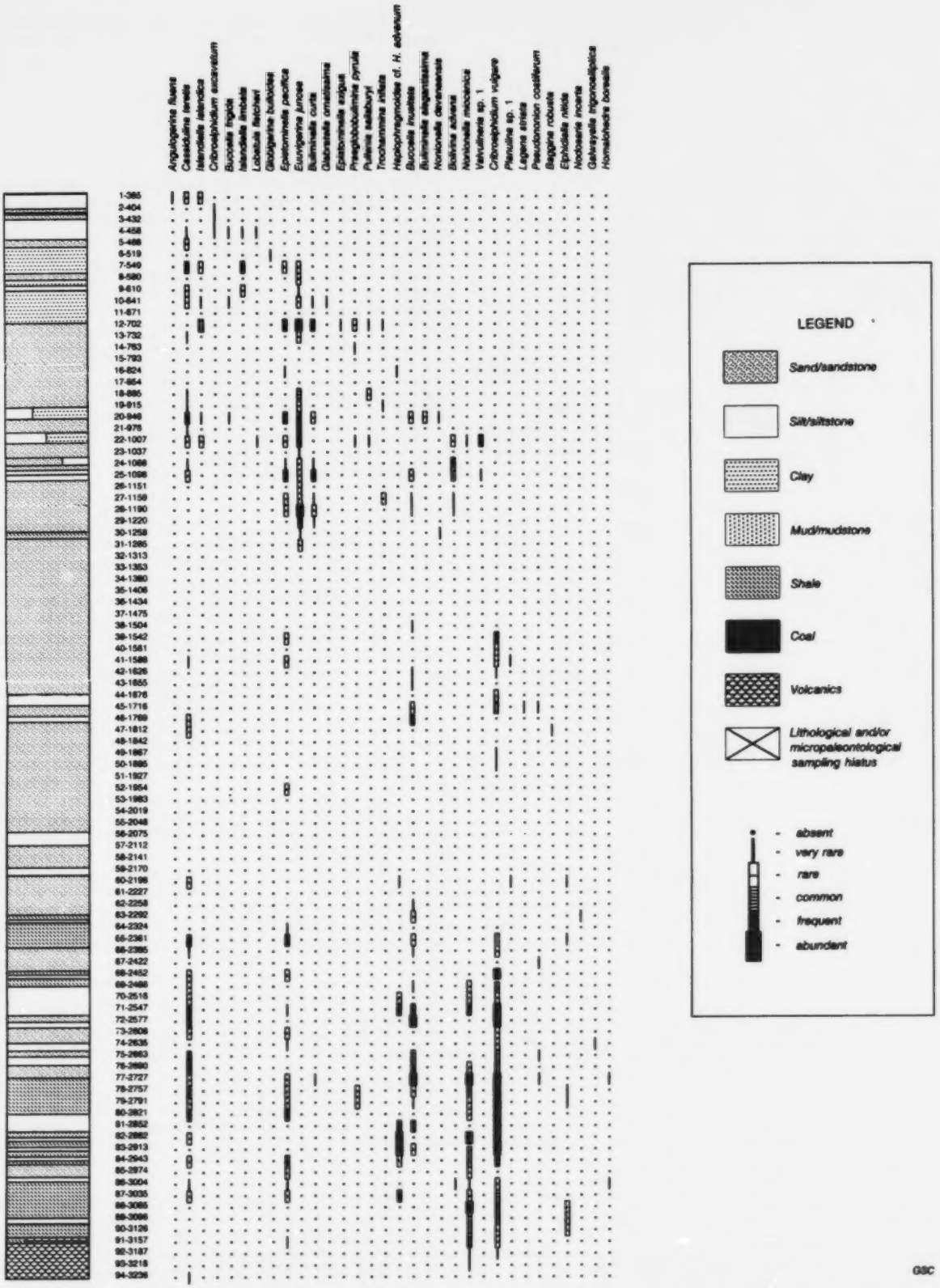


Figure 10.3. *Semiquantitative frequency distribution of benthic and planktonic Foraminifera from the Harlequin D-86 well in the Queen Charlotte Basin. Lithology summarized from Shell Canada Ltd. well history report.*

No foraminifers were found in samples 4 (402-411 m) through sample 33 (2107-2117 m). These samples correspond to the nonmarine interval of the well. Following the extensive faunal hiatus, taxa recovered from sample 34 (2145-2154 m) through sample 51 (2634-2637 m) represent a second foraminifer-bearing zone. Alternating marine and nonmarine conditions existed during this interval, as indicated by the coal seam at 2545 m. This zone is characterized by rare occurrences of the Miocene species *Cribroelphidium vulgare* (Voloshinova), 1952 first described from the Miocene of Sakhalin Island in the eastern U.S.S.R. (Voloshinova, 1952). All samples below this zone, sample 52 (2667-2670 m) through sample 60 (2911-2914 m) – the base of the sampled interval – are void. With the exception of the single specimen of *Procerolagena distoma* found in sample 1, the foraminiferal specimens from Murrelet L-15 are altered by diagenesis and are very poorly preserved. The effects of diagenesis are evident from the dark colour of many of the specimens (making them barely recognizable), and the very coarse texture of the calcite in their walls.

Harlequin D-86

Ninety-four samples ranging from 384 to 3237 m were examined from Harlequin D-86 (Fig. 10.3), which was spudded south of Murrelet L-15. A total of 32 foraminiferal taxa were identified in 75 samples; 19 samples were devoid of foraminifers. The fauna observed in Harlequin D-86 is better preserved than that found in Murrelet L-15. However, the faunas identified in sample 60 (2196-2206 m) and below have been diagenetically altered, and are difficult to identify due to poor preservation. Similar to the Foraminifera from the Murrelet L-15 well, the diagenetically altered specimens from Harlequin D-86 exhibit darkened tests and recrystallized calcite resulting in a coarse granular wall texture. Foraminifera are most abundant in the shale, siltstone, and clay units, being almost entirely absent in the sandy units.

Several species, such as *Cassidulina teretis* and *Epistominella pacifica* (Cushman), 1927 are fairly abundant and found throughout most of the interval. These species are therefore of little biostratigraphic use. *Buccella inusitata* Andersen, 1952, found in many samples from sample 20 (945-960 m) to sample 83 (2911-2914 m), is somewhat restricted in range. However, the species was originally described from Recent sediments in the Strait of Juan de Fuca (Andersen, 1952) and is therefore also of limited biostratigraphic use. This is the first report of this species in sediments older than Recent.

Other species are more restricted in range. *Cribroelphidium excavatum* (Terquem), 1876, common in modern shelf depth waters in the northeastern Pacific (Cockbain, 1963; Bergen and O'Neil, 1979), is very rare in sample 2 (404-413 m) through sample 4 (457-472 m). *Islandiella limbata* (Cushman and Hughes), 1925 is very rare to frequent in sample 4 (457-472 m) through sample 9 (610-6254 m). *Euuvigerina juncea*, first described from Pliocene sediments (Cushman and Todd, 1941), is very rare to abundant in most samples, beginning with sample 7 (549-564 m) through sample 31 (1284-1293 m). Both *Euuvigerina juncea* and *Islandiella limbata* are common in modern shallow waters along the Pacific west coast (Cockbain, 1963; Bergen and O'Neil, 1979; Douglas et al., 1979; Douglas, 1981). Other, even rarer, taxa were identified in the upper interval of Harlequin D-86. They include *Glabratella ornatissima* (Cushman), 1925, *Angulogerina fluens* (Todd), 1948, *Buliminella elegantissima* (d'Orbigny), 1939, and *Pullenia salisburyi* Stewart and Stewart, 1930. All of these species are presently common in neritic depth waters along the Pacific coast of North America (Todd and Low, 1967; Bergen and O'Neil, 1979; Douglas et al., 1979; Erskian and Lipps, 1987).

Several Miocene species also exhibit restricted ranges in Harlequin D-86. *Bolivina advena* Cushman, 1925, typical of lower (Saucesian Stage) to middle Miocene (Luisian Stage) sediments from California (Kleinpell, 1938; Kleinpell et al., 1980), is very rare to frequent in the short interval from sample 22 (1006-1021 m) to sample 28 (1189-1204 m). *Cribroelphidium vulgare* is very rare to abundant in many samples ranging from sample 39 (1541-1553 m) to sample 92 (3185-3188 m). Part of the range of *Euuvigerina juncea* overlaps the entire range of *Bolivina advena*. Although downhole contamination is an important concern when interpreting the fauna from this well, the presence of casing down to 1100 m would indicate that the overlap of these species is real and that *Euuvigerina juncea* probably has a much greater biostratigraphic range than previously known.

In Harlequin D-86, *Nonionella miocenica* also has a restricted range with a single, very rare occurrence in sample 20 (945-960 m), and then rare to abundant occurrences in sample 69 (2484-2487 m) through sample 93 (3216-3219 m). *Nonionella miocenica* is also restricted to Miocene samples from Osprey D-36. This species was first described in samples from the Miocene Monterey Formation of southern California (Cushman, 1925b). However, because *Nonionella miocenica* has also been identified in sediments from the Pliocene and Pleistocene of the Humboldt Basin of northern California (Haller in Kleinpell, 1980), its use as a biostratigraphic marker is questionable. Other characteristic Miocene taxa, such as *Pseudononion costiferum* (Cushman), 1926, *Transversigerina transversa* (Cushman), 1918, and *Uvigerinella ornata* Cushman, 1926, common in many samples from the Osprey D-36 well, are absent or very rare in Harlequin D-86. The increase in abundance toward the base of the well of such taxa as *Nonionella miocenica*, *Buccella inusitata* and *Cribroelphidium vulgare* indicates that these species are probably *in situ* and have not been reworked downhole. The volcanic unit at the base of the well, below 3149 m, is not homogeneous, but instead consists of beds of volcanics, and volcanic debris interbedded with shale and other sediment. The few Foraminifera found in this unit may very well also be *in situ*.

Osprey D-36

One hundred and forty-two samples, from depths of between 298 and 2530 m, were examined from Osprey D-36, the most southerly of the wells analyzed in this study (Fig. 10.4). One hundred and fourteen samples yielded 35 species of Foraminifera; 28 samples were devoid of any fauna. Specimens in all samples, although commonly broken, are very well preserved and exhibit no effects of the diagenesis that characterized the faunas recovered from Murrelet L-15 and Harlequin D-86. The foraminiferal fauna found in Osprey D-36 is similar to that observed in the other two wells; however, the various taxa identified in this well tend to be more abundant. As in the Harlequin D-86 well, Foraminifera are almost entirely absent from the sandy units. Extensive volcanic units are also observed in the lower intervals of this well. However, as these units are primarily pyroclastic sediments rather than solid basalts, it is probable that most Foraminifera identified in these units are *in situ* and not reworked from above.

As observed in Harlequin D-86, *Cassidulina teretis* and *Epistominella pacifica* range throughout the entire sampled interval. Other identifiable taxa, however, form two distinct faunal associations associated with the upper and lower parts

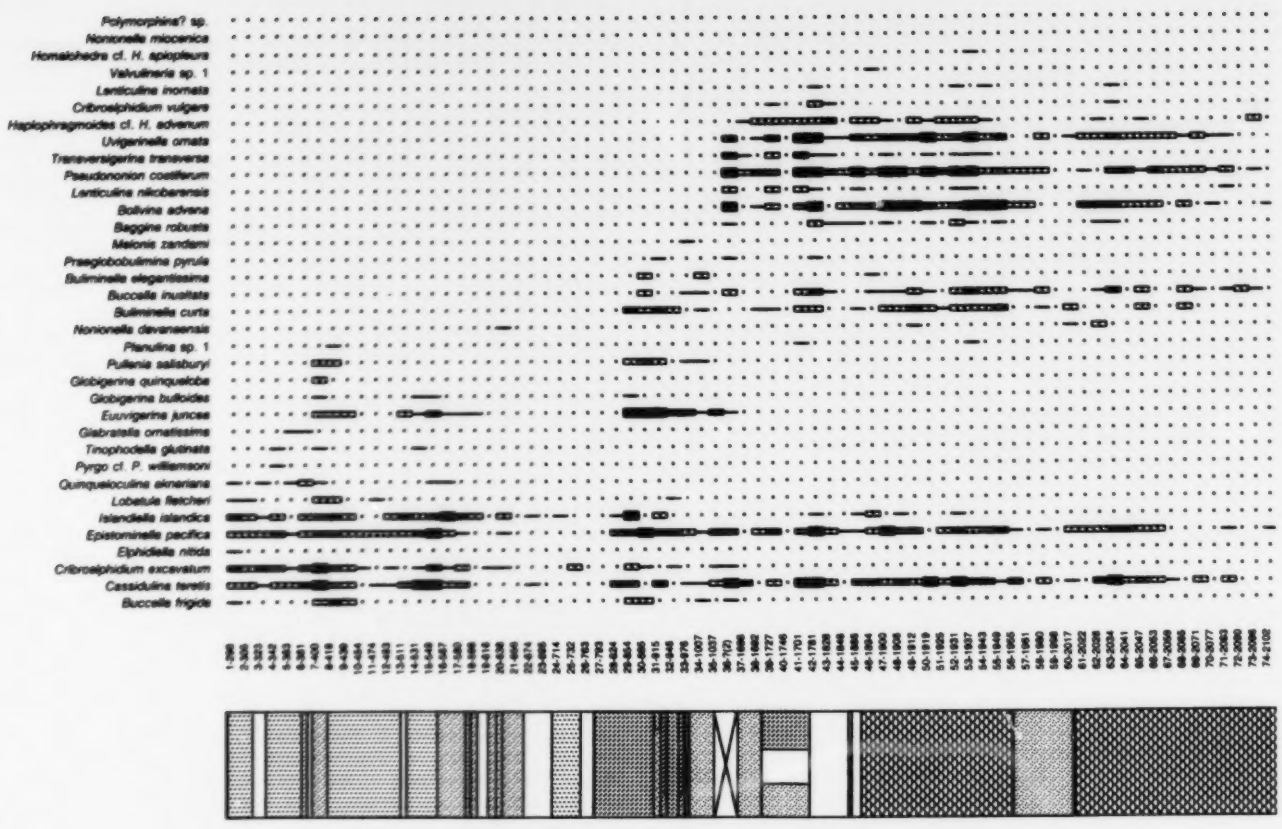


Figure 10.4. *Semiquantitative frequency distribution of benthic and planktonic Foraminifera from the Osprey D-36 well in the Queen Charlotte Basin. Lithology summarized from Shell Canada Ltd. well history report.*

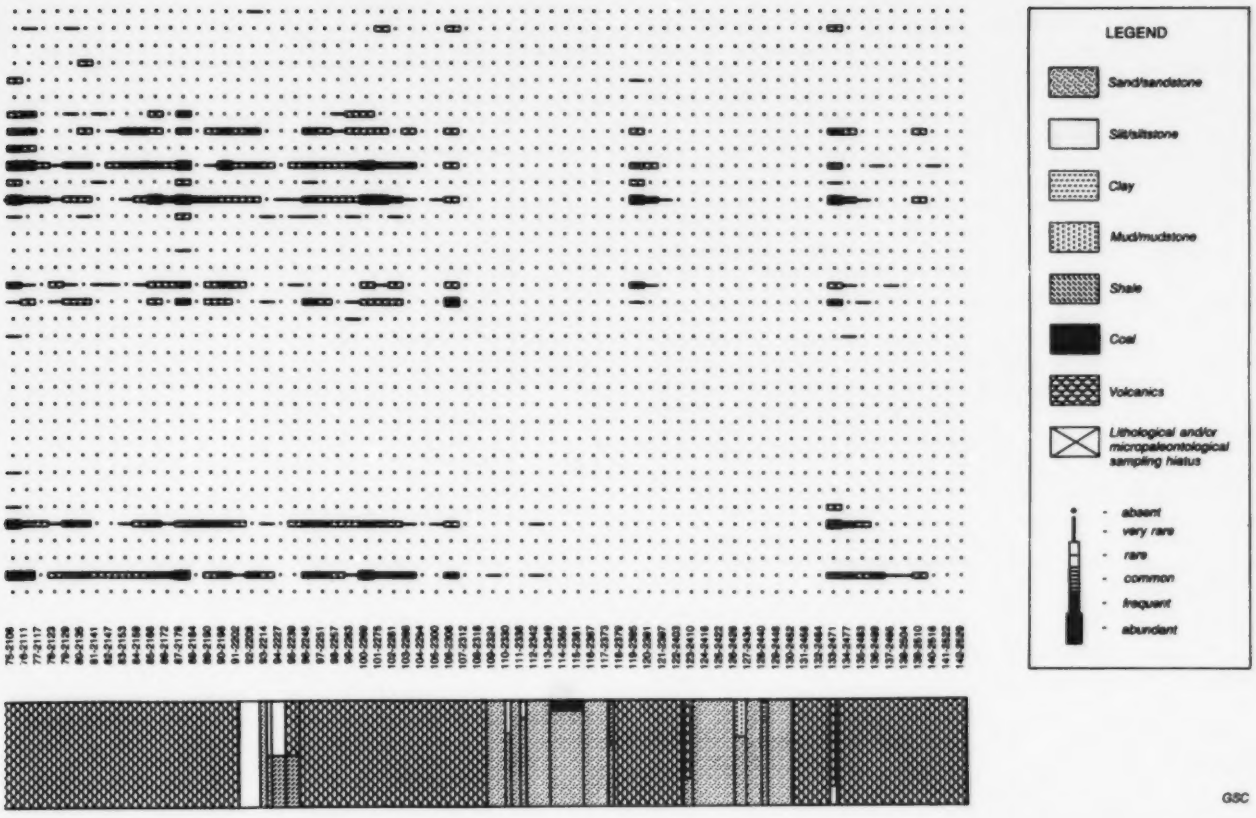
of the well. Unfortunately, a large sampling gap of 632 m, probably caused by the extensive cave-ins in this interval during drilling, separate the two zones. The sampling gap is between sample 35 (1036-1052 m) and sample 37 (1687-1697 m). Sample 36 (2), obtained from an unknown depth within this gap, contains elements of both a modern boreal fauna (upper part of the well) and an early Miocene fauna (sample 36 and below), indicating probable contamination from above.

The upper zone of Osprey D-36 had a fauna similar to that found in Recent shallow shelf waters of the northeastern Pacific Ocean (Cockbain, 1963; Bergen and O'Neil, 1979). This zone extends from the top of the sampled section to sample 35 (1036-1052 m), and is characterized by various boreal species such as *Buccella frigida* (Cushman), 1922. *Cribroelphidium excavatum* and *Euuvigerina juncea*, which were very rare to abundant in most samples from the upper interval, also characterize the zone. Very rare occurrences of the shallow water indicator species *Glabratella ornatissima* and *Melonis zandami* Van Voorthuysen, 1950 were also found in the upper unit.

The lower zone of the well extends from sample 37 (1687-1697 m) to the base of the section. This zone contains characteristic lower to middle Miocene foraminifers, in addition to the two long-ranging taxa identified above. The species that best delineat this zone were *Bolivina advena*, *Pseudononion costiferum* and *Uvigerinella ornata*. *Bolivina advena* is abundant in many samples from the top of the lower zone, beginning at sample 37 (1687-1697 m), to near the base of the sampled interval. *Pseudononion costiferum* is also very abundant in the upper samples of this interval. Kleinpell et al. (1980) reported that these two species range from the early Miocene Saucesian Stage to the middle Miocene Luisian Stage.

A large increase in the number of Foraminifera is observed at 2106 m in Osprey D-36. This increase is most likely due to downhole contamination as log runs 2 and 3 meet at this level. Downhole contamination typically occurs immediately following a logging operation, as after drilling mud circulation renews, there is a tendency for any material that caved into the hole during the operation to be deposited on the shale shaker (J. White, pers. comm., 1988).

Uvigerinella ornata, which is very rare to abundant in the lower zone of Osprey D-36, has been identified by Kleinpell et al. (1980) in samples from the Saucesian Stage to Luisian Stage. Another important indicator species in the lower interval of Osprey D-36, *Transversigerina transversa* (Cushman), 1918, is somewhat less common. Kleinpell et al. (1980) reported that the range of this species is even more restricted than that of the other indicator species identified above, as it is found only in the Saucesian and the overlying late early Miocene Relizian Stage. *Nonionella miocenica* and *Cribroelphidium vulgare*, which are notably common in the lower part of the Harlequin D-86 well, are present in only a few samples from the lower zone of Osprey D-36.



In both the upper Plio-Pleistocene boreal fauna-bearing interval and the lower early Miocene fauna-bearing interval of Osprey D-36, there are rare occurrences of the neritic dwelling species *Buliminella elegantissima* and *Praeglobobulimina pyrula* (d'Orbigny, 1846). Generally, the presence of these species in both the upper and lower intervals of the well would indicate downhole contamination. However, the presence of the casing down to 1056 m in the well negates the possibility of such contamination, and suggests that these species may have ranged over the entire depositional interval.

DISCUSSION

In general, because the total number of identifiable taxa is quite small – only forty-two species – it is difficult to determine the precise bathymetric ranges and ages of the fauna from the three wells. For example, only two species are found in samples from the upper fauna-bearing zone of the Murrelet L-15 well. In addition, the low numbers of specimens obtained from each sample, coupled with major zones of nonrecovery, make it difficult to arrive at a precise paleoenvironmental interpretation.

Pliocene-Quaternary

The upper faunal zones of Osprey D-36 [sample 1 (298 m) through sample 35 (1036-1052 m)], Harlequin D-86 [sample 1 (385 m) through sample 21 (975-991 m)], and Murrelet L-15 [sample 1 (329-336 m) through sample 3 (374-383 m)] consist entirely of extant species common in the coastal waters along the northern part of the west coast of North America. Many of those species also existed in the Pliocene. However, because no definitive Pliocene or Quaternary taxa are present in all of these intervals, they must be classified as Plio-Quaternary (Fig. 10.5).

The water depth of the upper fauna-bearing zone of the Osprey D-36 well was probably somewhere between middle neritic (50-100 m) and outer neritic (100-200 m), based on studies of similar fauna from California to the Gulf of Alaska (Cockbain, 1963; Bergen and O'Neil, 1979; Douglas et al., 1979; Douglas, 1981; and others). Bergen and O'Neil (1979) reported that species such as *Cribroelphidium excavatum*, *Glabratella ornatissima*, *Buliminella elegantissima*, and *Buccella frigida* were most common in waters less than 100 m deep, whereas species such as *Epistominella pacifica* and *Euuvigerina juncea* were most common at the shallower limit of the outer neritic zone, a water depth of approximately 100 m. A study of Recent Foraminifera from the California borderland found several of these boreal species in slightly deeper habitats, which was probably due to the warmer water temperature of this area (Douglas, 1981). For example, Douglas (1981) found that *Euuvigerina juncea* was characteristic of the upper slope (in water depths of 85-450 m), while *Buccella frigida* was most common on offshore ridges and deep banks at depths of 100 to 400 m. Thus, assuming that the sediments from the upper zone of the Osprey D-36 well are Plio-Quaternary, cool water temperatures, and depths of approximately 100 to 200 m, probably prevailed throughout this interval of deposition in the Queen Charlotte Basin (Figs. 10.4, 10.5).

The fauna identified from the upper zone of the Harlequin D-86 well (sample 1 to sample 21) is similar to that found in the upper interval of Osprey D-36. The boreal fauna found in this zone differs from that identified in Osprey D-36 only in the decreased total number of specimens recovered, which is characteristic of all samples from Harlequin D-86. The specimens in this upper interval are well preserved, indicating very little diagenetic alteration. Because the fauna from the upper (Plio-Quaternary) zone of Harlequin D-86 are similar to that recovered from the upper (Plio-Quaternary) zone of Osprey D-36, the water depth during deposition of the Harlequin D-86 upper interval (Figs. 10.3, 10.5) was most likely neritic (100-200 m).

Interpreting the fauna from the upper zone of Murrelet L-15 (samples 1 through 3) was nearly impossible as only three specimens, consisting of two species, *Procerolagena distoma* and *Cassidulina teretis*, were recovered. These species are found in neritic and bathyal environments (Tappan, 1952; Mackensen and Hald, 1988), and range from the Miocene to Recent. Thus, based on the varied habitats and range of these species, it is difficult to determine the depositional environment of the upper unit of Murrelet L-15. However, because the specimens recovered from this zone are better preserved than the fauna found in the lower faunal interval of the core, they are probably late Plio-Quaternary in age. The fact that these sediments were deposited above the upper Miocene-Pliocene nonmarine zone of the Murrelet L-15 well (Shouldice, 1971) supports this conclusion (Figs. 10.2, 10.5).

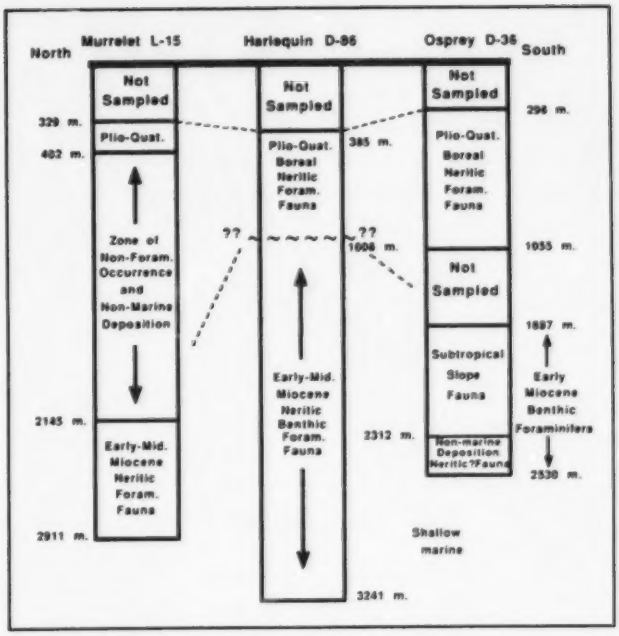


Figure 10.5. *Foraminiferal distribution in the Osprey D-36, Harlequin D-86, and Murrelet L-15 wells from the Queen Charlotte Basin off the west coast of British Columbia.*

Miocene

Miocene foraminifers were found in samples from all three wells. In Osprey D-36, the foraminifer specimens recovered from sample 37 (1687-1697 m) to the base of the section were well developed and included several Miocene species. The Miocene species identified from this interval were *Bolivina advena*, *Pseudononion costiferum*, *Cribroelphidium vulgare*, *Lenticulina nikobarensis*, *Transversigerina transversa* and *Uvigerinella ornata*. Unfortunately, a major sampling gap of more than 600 m occurs between samples 35 to 37 (Figs. 10.4, 10.5) of the Osprey D-36 well.

Bolivina advena, *Uvigerinella ornata*, *Pseudononion costiferum*, and *Transversigerina transversa* all first appeared in the Saucesian Stage of the early Miocene (Kleinpell, 1938; Kleinpell et al., 1980). *Uvigerinella ornata* and *Pseudononion costiferum* had disappeared by the middle Miocene Luisian. *Bolivina advena* has been found in the late Miocene Mohnian Stage of California, while *Transversigerina transversa* had disappeared by the end of the Relizian Stage of the late early Miocene. Assuming that the ranges of *Bolivina advena* and *Transversigerina transversa* off British Columbia are similar to those of the California species, the sediments of Osprey D-36 containing these species could not have been deposited later than the early Miocene.

The Miocene interval of Osprey D-36 can be separated into two distinct units. The presence of *Transversigerina transversa* in the upper part of the Miocene section – above 2312 m – suggests that warmer water temperatures and upper to middle bathyal depths prevailed during deposition of this interval. *Uvigerinella ornata* abundant in this upper unit as well, also indicates the existence of upper to middle bathyal water depths ranging from approximately 200 to 1500 m (Kleinpell, 1938; Kleinpell et al., 1980).

The lower unit – below 2314 m – of the Miocene interval of the Osprey D-36 well is characterized by alternating regions of foraminifer-bearing zones and thick sandstone sections devoid of any fauna (Figs. 10.4, 10.5). The presence of coal at 2347 to 2362 m, within a thick sandstone unit at 2312 to 2379 m, suggests that there may have been at least one episode of continental deposition. In addition, a lower, sandstone unit (2403-2464 m) may also represent another period of continental deposition. In the foraminifer-bearing zones, the upper to middle bathyal indicator species *Transversigerina transversa* is absent, which suggests that the lower section may have been deposited in water more shallow than that associated with deposition of the upper part of the Miocene interval. However, the presence of the deeper dwelling *Uvigerinella ornata* in these samples may indicate that the absence of *Transversigerina transversa* is related to other factors besides depth. Thus, the samples from beneath 2312 m at Osprey D-36 most likely record alternating marine transgressive and continental regressive depositional events.

The Miocene fauna recovered from the Harlequin D-86 well – sample 22 (1005-1021 m) to the base of the section – is similar to that found above the 2312 m level in Osprey D-36. However, both *Transversigerina transversa* and *Uvigerinella ornata* are entirely absent in Harlequin D-86. One possible explanation for the absence of *Transversigerina transversa* is that the Miocene section of Harlequin D-86 was deposited after the extinction of this species and is thus wholly Luisian. This hypothesis, however, does not explain the absence of *Uvigerinella ornata*, which is found in the Luisian. Because both *Transversigerina transversa* and *Uvigerinella ornata* are moderately deep water dwelling species (Kleinpell, 1938; Kleinpell et al., 1980), a more probable explanation for their absence is that the depositional environment of the Harlequin D-86 Miocene section was possibly of neritic depth <200 m,

and thus shallower than the younger Miocene section of Osprey D-36. Such a conclusion accounts for the predominance of *Cribroelphidium vulgare* in this section because, although species of *Elphidium* de Montfort, 1808 and related genera are found at many depths, they are most common in shallow, inner shelf environments (Haynes, 1981). As in Osprey D-36, water temperatures associated with the Miocene interval of Harlequin D-86 were most likely warm. The difference in identifiable fauna found in the two wells could therefore be attributed solely to a shift in water depth, assuming that the two sections were deposited at approximately the same time (Figs. 10.3, 10.5). An interesting feature of the Harlequin D-86 well is that the Miocene fauna was located immediately below the Plio-Quaternary foraminifers. The late Miocene to Pliocene regional unconformities in the Queen Charlotte Basin postulated by Shouldice (1971), based on seismic evidence, mostly likely cause this juxtaposition.

In Murrelet L-15, a Miocene fauna was obtained from sample 34 (2196-2206 m) through sample 52 (2634-2637 m), an area below the nonmarine depositional zone of the well (Shouldice, 1971). Interpretation of the Miocene interval is difficult as the recovered fauna consists of only four species: *Cassidulina teretis, Buccella inusitata, Elphidiella nitida,* and *Cribroelphidium vulgare.* Of the four species, *Cribroelphidium vulgare* is the most abundant, and the only taxon that is restricted to the Miocene. The dominance of *Cribroelphidium vulgare* indicates a neritic depositional environment for the lower unit of Murrelet L-15, similar to that determined for the Miocene interval of Harlequin D-86 (Figs. 10.2, 10.5). Moreover, the early Miocene foraminiferal fauna found in the lower intervals of both the Murrelet L-15 and Harlequin D-86 below [sample 60 (2196-2206 m)] wells had been recrystallized to a coarse granular texture, and generally was light to dark brown in colour. This diagenetic alteration suggests that as one moves north in the basin there is greater geochemical and thermal maturity of the sediments, indicating a higher probability of hydrocarbons (Hunt, 1979).

A paleoenvironmental interpretation of the various wells that have been drilled in the Queen Charlotte Basin was postulated by Yorath and Hyndman (1983) based on regional geological, geophysical, and heat flow data. Yorath and Hyndman determined that the early Miocene part of the Osprey D-36 well had been deposited in bathyal depths (600-1750 m), and that the Murrelet L-15 well was deposited under shallow marine conditions. This is in concordance with the conclusions reached in the present study. Yorath and Hyndman (1983), however, posited that the early Miocene part of the Harlequin D-86 well and the early Miocene section beneath 2312 m at Osprey D-36 were deposited at bathyal depths, similar to the stratigraphically higher Miocene deposits at Osprey D-36. As discussed above, however, the close similarity of the shallow-water dwelling foraminiferal fauna found in the early Miocene parts of the Harlequin D-86 and Murrelet L-15 wells, and their dissimilarity from the early Miocene fauna from the Osprey D-36 well indicate that the depositional environment of Harlequin D-86 during this time was neritic. In addition, the presence of coal in the nonforaminifer-bearing sandstone, and the absence of *Transversigerina transversa* from the adjacent foraminifer-bearing intervals in the Miocene section below 2312 m in Osprey D-36, suggest that the depositional environment of at least part of this interval may also have been continental, and/or shallow marine.

SYSTEMATIC PALEONTOLOGY

Taxa are listed in alphabetical order. Generic designations follow those of Loeblich and Tappan (1987).

Angulogerina fluens Todd

Plate 10.3, figures 1, 2

Angulogerina fluens Todd, in Cushman and Todd, 1947, p. 67, Pl. 16, figs. 6, 7 (nomen nudum).

Angulogerina fluens Todd, in Cushman and McCulloch, 1948, p. 288.

Baggina robusta Kleinpell

Plate 10.6, figures 4-6

Baggina robusta Kleinpell, 1938, p. 325, Pl. 11, fig. 8; Pl. 13, fig. 2.

Bolivina advena Cushman

Plate 10.8, figures 7-10

Bolivina advena Cushman, 1925b, p. 29, Pl. 5, fig. 1.

Bolivina advena Cushman var. *ornata* Cushman, 1925b, p. 29, Pl. 5, fig. 2.

Bolivina advena Cushman var. *striatella* Cushman, 1925b, p. 30, Pl. 5, fig. 3.

Buccella frigida (Cushman)

Plate 10.7, figures 4-6

Pulvinulina frigida Cushman, 1922, p. 470.

Buccella frigida (Cushman). Andersen, 1952, p. 144, Textfigs. 4-6.

Buccella inusitata Andersen

Plate 10.7, figures 1-3

Buccella inusitata Andersen, 1952, p. 148, Textfigs. 10, 11.

Buliminella curta Cushman

Plate 10.5, figures 1, 2

Buliminella curta Cushman, 1925, p. 33, Pl. 5, fig. 13.

Buliminella elegantissima (d'Orbigny)

Plate 10.3, figure 11

Bulimina elegantissima d'Orbigny. 1839, p. 51, Pl. 7, figs. 13, 14.

Buliminella elegantissima (d'Orbigny). Cushman, 1919, p. 606.

Cassidulina teretis Tappan

Plate 10.5, figure 4

Cassidulina laevigata d'Orbigny. Brady, 1884, p. 428, Pl. 54, figs. 1-3 (not d'Orbigny, 1826).

Cassidulina teretis Tappan, 1951, p. 7, Pl. 1, fig. 30a-c.

Cribroelphidium excavatum (Terquem)

Plate 10.10, figures 4-9; Plate 10.11, figures 1, 2

Polystomella excavata Terquem, 1876, p. 25, Pl. 2, fig. 2a-f.

Elphidium incertum (Williamson) var. *clavatum* Cushman, 1930, p. 20, Pl. 7, fig. 10.

Elphidium clavatum Cushman. Loeblich and Tappan, 1953, p. 98, 101, 102, Pl. 19, figs. 8-10.

Elphidium excavatum (Terquem) forma *clavata* Cushman. Miller, Scott and Medioli, 1982, p. 124-128, Pl. 1, figs. 5-8; Pl. 2, figs. 3-8; Pl. 3, figs. 3-8; Pl. 4, figs. 1-7; Pl. 5, figs. 4-8; Pl. 6, figs. 1-5.

Cribroelphidium vulgare (Voloshinova)

Plate 10.9, figures 7-9; Plate 10.10, figures 1, 2

Elphidium vulgare var. *vulgare* Voloshinova, 1952, p. 53, Pl. 8, figs. 3-8.

Elphidiella nitida Cushman

Plate 10.10, figure 3

Elphidiella nitida Cushman, 1941, p. 35, Pl. 9, fig. 4.

Elphidiella nitida Cushman. Loeblich and Tappan, 1953, p. 107, 108, Pl. 19, figs. 11, 12.

Elphidiella nitida Cushman. Bergen and O'Neil, 1979, Pl. 1, figs. 3, 4.

Epistominella pacifica (Cushman)

Plate 10.6, figures 1-3

Pulvinulina pacifica Cushman, 1927, p. 165, Pl. 5, figs. 14, 15.

Euuvigerina juncea (Cushman and Todd)

Plate 10.3, figures 3-5

Uvigerina juncea Cushman and Todd, 1941, p. 78, Pl. 20, figs. 4-11.

Galwayella trigonoelliptica (Balkwill and Millett)

Plate 10.4, figure 9

Lagena trigono-elliptica Balkwill and Millett, 1884, p. 81, 87, Pl. 3, fig. 8.

Glabratella ornatissima (Cushman)

Plate 10.5, figures 6-9

Discorbis ornatissima Cushman, 1925, p. 42, Pl. 6, figs. 11, 12.

Trichohyalus pustulata Loeblich and Tappan, 1953, p. 118, Pl. 23, figs. 8, 9.

Glabratella ornatissima (Cushman). Erskian and Lipps, 1987, p. 243, Pl. 1, figs. 1-8.

Globigerina bulloides d'Orbigny

Plate 10.11, figures 4, 5

Globigerina bulloides d'Orbigny, 1826, p. 277.

Globigerina bulloides d'Orbigny. d'Orbigny, 1839b, p. 132-133, Pl. 2, figs. 1, 3, 28.

Haplophragmoides cf. *H. advenum* Cushman

Plate 10.1, figures 4, 5, 7, 8

Haplophragmoides advena Cushman, 1925, p. 38, Pl. 6, fig. 1.

Homalohedra cf. *H. apiopleura* (Loeblich and Tappan)

Plate 10.4, figure 4

Lagena apiopleura Loeblich and Tappan, 1953, p. 59, Pl. 10, figs. 14, 15.

Homalohedra borealis (Loeblich and Tappan)

Plate 10.4, figure 7

Entosolenia costata Williamson, 1858, p. 9, Pl. 1, fig. 18.

Oolina costata (Williamson). Loeblich and Tappan, 1953, p. 68, Pl. 13, figs. 4-6 (not *Oolina costata* Egger, 1857).

Oolina borealis Loeblich and Tappan, 1954, p. 384.

Islandiella islandica (Nørvang)

Plate 10.5, figure 5

Cassidulina islandica Nørvang, 1945, p. 41, Textfigs. 7, 8d-f.

Islandiella limbata (Cushman and Hughes)

Plate 10.5, figure 3

Cassidulina limbata Cushman and Hughes, 1925, p. 12, Pl. 2, fig. 2.

Lagena striata (d'Orbigny)

Plate 10.4, figure 5

Oolina striata d'Orbigny, 1839, p. 21, Pl. 5, fig. 12.

Lenticulina inornata (d'Orbigny)

Plate 10.2, figures 4, 5

Robulina inornata d'Orbigny, 1846, p. 102, Pl. 4, figs. 25, 26.

Lenticulina nikobarensis (Schwager)

Plate 10.2, figures 7, 8

Cristellaria nikobarensis Schwager, 1866, p. 243, Pl. 6, fig. 87.

Robulus cushmani Galloway and Wissler, 1927, p. 51, Pl. 8, fig. 11.

Robulus nikobarensis (Schwager). Todd and Low, 1967, p. A21, Pl. 3, figs. 2, 3.

Lobatula fletcheri (Galloway and Wissler)

Plate 10.7, figures 7-9

Cibicides fletcheri Galloway and Wissler, 1927, p. 64, Pl. 10, figs. 8, 9.

Melonis zandami (van Voorthuysen)

Plate 10.8, figures 3, 4

Nonion barleeanum (Williamson) var. *inflatum* van Voorthuysen, 1950, p. 41, Textfig. 7, Pl. 3, fig. 6a, b (non *Nonionina inflata* Alth, 1850).

Anomalinoides barleeanum (Williamson) var. *zandamae* van Voorthuysen, 1952, p. 681.

Nodosaria incerta Neugeboren

Plate 10.2, figures 3, 6

Nodosaria incerta Neugeboren, 1856, p. 72, Pl. 1, figs. 10, 11.

Nonionella miocenica Cushman

Plate 10.8, figures 11-13

Nonionina auris Cushman, 1926, p. 91, Pl. 13, fig. 4a-c.

Nonionella miocenica Cushman, 1926, p. 64.

Nonionella davanaensis (Pierce)

Plate 10.9, figures 1-3

Nonionella davanaensis Pierce, 1956, p. 1303, Pl. 137, fig. 10.

Planulina sp. 1

Plate 10.8, figures 1, 2

Polymorphina? sp.

Plate 10.4, figures 3, 6

Praeglobobulimina pyrula (d'Orbigny)

Plate 10.3, figure 10

Bulimina pyrula d'Orbigny, 1846, p. 184, Pl. 11, figs. 9, 10.

Procerolagena distoma (Parker and Jones)

Plate 10.4, figure 8

Lagena distoma Parker and Jones, in Brady, 1864, p. 467, Pl. 48, fig. 6.

Pseudononion costiferum (Cushman)

Plate 10.9, figures 4-6

Nonionina costifera Cushman, 1926, p. 90, Pl. 13, fig. 2.

Pullenia salisburyi Stewart and Stewart

Plate 10.8, figures 5, 6

Pullenia salisburyi Stewart and Stewart, 1930, p. 72, Pl. 8, fig. 2.

Pyrgo cf. *P. williamsoni* (Silvestri)

Plate 10.2, figures 1, 2

Biloculina ringens (Lamarck) typica Williamson, 1858, p. 79, Pl. 6, figs. 169, 170; Pl. 7, fig. 171 (non *Miliolites ringens* Lamarck, 1804).

Biloculina williamsoni Silvestri, 1923, p. 73.

Quinqueloculina akneriana d'Orbigny

Plate 10.1, figures 6, 9

Quinqueloculina akneriana d'Orbigny, 1846, p. 290, Pl. 18, figs. 16-21.

Tinophodella glutinata (Egger)

Plate 10.11, figures 3, 6

Globigerina glutinata Egger, 1893, p. 371, Pl. 13, figs. 19-21.

Transversigerina transversa (Cushman)

Plate 10.4, figures 1, 2

Siphogenerina raphanus (Parker and Jones) var. *transversus* Cushman, 1918, p. 64, Pl. 22, fig. 8.

Trochammina inflata (Montagu)

Plate 10.1, figures 1-3

Nautilus inflatus Montagu, 1808, p. 81, Pl. 18, fig. 3.

Uvigerinella ornata (Cushman)

Plate 10.3, figures 6-9

Uvigerina (Uvigerinella) californica Cushman var. *ornata* Cushman, 1926, p. 59, Pl. 8, figs. 1, 6.

Valvulineria sp. 1

Plate 10.6, figures 7-9

Valvulineria araucana (d'Orbigny) Kleinpell, 1980, Pl. 5, fig. 3 (non *Rosalina araucana* d'Orbigny, 1939).

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APPENDIX 1

Shell Anglo Murrelet L-15 sample intervals in Imperial and metric units

	Feet	Metres		Feet	Metres
1.	1080-1105	329-337	31.	6576-6665	2004-2032
2.	1138-1164	347-335	32.	6791-6881	2070-2097
3.	1228-1258	374-383	33.	6913-6944	2107-2117
4.	1318-1349	402-411	34.	7037-7067	2145-2154
5.	1440-1472	439-449	35.	7126-5156	3172-2181
6.	1553	467	36.	7220-7250	2201-2210
7.	1623-1651	495-503	37.	7311-7341	2228-2238
8.	1730-1760	527-537	38.	7407	2349
9.	1820-1851	555-564	39.	7556-7580	2303-2310
10.	1913-1943	583-592	40.	7590-7600	2313-2317
11.	2033-2063	619-629	41.	7640-7650	2329-2332
12.	2129-2159	649-658	42.	7740-7750	2359-2362
13.	2224-2225	678-687	43.	7840-7850	2390-2393
14.	2344-2376	715-724	44.	7940-7950	2420-2423
15.	2435-2465	742-751	45.	8050-8060	2454-2457
16.	2528-2558	771-780	46.	8160-8170	2487-2490
17.	2620-2652	799-808	47.	8240-8250	2512-2515
18.	2716-2748	828-838	48.	8340-8350	2542-2545
19.	2810-2841	857-866	49.	8450-8460	2576-2579
20.	2935-2965	895-904	50.	8550-8560	2606-2609
21.	3024-3054	922-931	51.	8640-8650	2634-2637
22.	3115-3145	950-959	52.	8750-8760	2667-2670
23.	3204-3235	977-986	53.	8850-8860	2698-2701
24.	3327-3358	1014-1024	54.	8950-8960	2728-2731
25.	3420-3451	1042-1052	55.	9050-9060	2758-2762
26.	3514-3545	1071-1081	56.	9150-9160	2789-2792
27.	3617-3663	1103-1117	57.	9250-9260	2819-2823
28.	3724-3754	1135-1144	58.	9350-9360	2850-2853
29.	3815-3845	1163-1172	59.	9450-9460	2880-2883
30.	5450-5500	1661-1676	60.	9550-9560	2911-2914

APPENDIX 2

Shell Anglo Harlequin D-86 sample intervals in Imperial and metric units

1.	1263	385	28.	3900-3950	1189-1204
2.	1324-1355	404-413	29.	4000-4050	1219-1234
3.	1415-1450	431-442	30.	4122-4152	1256-1266
4.	1500-1550	457-472	31.	4213-4243	1284-1293
5.	1600-1650	488-503	32.	4305-4346	1312-1325
6.	1700-1750	518-533	33.	4435-4490	1352-1369
7.	1800-1850	549-564	34.	4523-4554	1379-1388
8.	1900-1950	579-594	35.	4611-4641	1405-1415
9.	2000-2050	610-625	36.	4703-4733	1434-1443
10.	2100-2150	640-655	37.	4835-4866	1474-1483
11.	2200-2250	671-686	38.	4930-4963	1503-1513
12.	2300-2350	701-716	39.	5055-5094	1541-1553
13.	2400-2450	732-747	40.	5117-5150	1560-1570
14.	2500-2550	762-777	41.	5207-5245	1587-1599
15.	2600-2650	793-808	42.	5331-5363	1625-1939
16.	2700-2750	823-838	43.	5427-5457	1654-1663
17.	2800-2850	853-869	44.	5495-5563	1675-1696
18.	2900-2950	884-899	45.	5626-5658	1715-1725
19.	3000-3050	914-930	46.	5800-5820	1768-1774
20.	3100-3150	945-960	47.	5940-6000	1811-1829
21.	3200-3250	975-991	48.	6040-6100	1841-1859
22.	3300-3350	1006-1021	49.	6120-6180	1865-1884
23.	3400-3450	1036-1052	50.	6180-6280	1884-1902
24.	3500-3550	1067-1082	51.	6317-6348	1925-1935
25.	3600-3650	1097-1113	52.	6408-6438	1953-1962
26.	3775	1151	53.	6500-6554	1981-1998
27.	3800-3850	1158-1174	54.	6621-6684	2018-2037

	Feet	Metres		Feet	Metres
55.	6715-6745	2047-2056	75.	8730-8760	2661-2670
56.	6804-6833	2074-2083	76.	8820-8870	2688-2704
57.	6926-6958	2111-2121	77.	8940-8950	2725-2728
58.	7019-7051	2139-2149	78.	9040-9050	2755-2758
59.	7113-7144	2168-2178	79.	9150-9160	2789-2792
60.	7205-7237	2196-2206	80.	9250-9260	2819-2823
61.	7303-7335	2226-2236	81.	9350-9360	2850-2853
62.	7402-7436	2256-2266	82.	9450-9460	2880-2883
63.	7514-7534	2290-2296	83.	9550-9560	2911-2914
64.	7620-7640	2323-2329	84.	9650-9660	2941-2944
65.	7740-7750	2359-2362	85.	9750-9760	2972-2975
66.	7820-7871	2384-2399	86.	9850-9860	3002-3005
67.	7940-7960	2420-2426	87.	9950-9960	3033-3036
68.	8040-8050	2451-2454	88.	10050-10060	3063-3066
69.	8150-8160	2484-2487	89.	10150-10160	3094-3097
70.	8250-8260	2515-2518	90.	10250-10260	3124-3127
71.	8350-8360	2545-2548	91.	10350-10360	3155-3158
72.	8450-8460	2576-2579	92.	10450-10460	3185-3188
73.	8550-8560	2606-2609	93.	10550-10560	3216-3219
74.	8640-8660	2634-2640	94.	10610-10620	3234-3237

APPENDIX 3

Shell Anglo Osprey D-36 sample intervals in Imperial and metric units

1.	970	296	43.	5994-6026	1827-1837
2.	1000-1030	305-314	44.	6058-6090	1846-1856
3.	1060-1090	323-332	45.	6183-6200	1885-1890
4.	1120-1160	341-354	46.	6210-6220	1893-1896
5.	1190-1220	363-372	47.	6230-6240	1899-1902
6.	1250-1280	381-390	48.	6250-6260	1905-1908
7.	1310-1340	399-408	49.	6270-6279	1911-1914
8.	1370-1400	418-427	50.	6290-6300	1917-1920
9.	1430-1460	436-445	51.	6310-6320	1923-1926
10.	1489-1526	454-465	52.	6330-6340	1929-1932
11.	1555-1584	474-483	53.	6350-6360	1936-1939
12.	1616-1646	493-502	54.	6370-6380	1942-1945
13.	1676-1710	511-521	55.	6390-6400	1948-1951
14.	1740-1772	530-540	56.	6410-6420	1954-1957
15.	1799-1830	548-558	57.	6430-6461	1960-1969
16.	1860-1891	567-576	58.	6492-6521	1979-1988
17.	1900-1930	579-588	59.	6551-6582	1997-2006
18.	1960-1990	597-607	60.	6613-6620	2016-2018
19.	2020-2060	616-628	61.	6630-6640	2021-2024
20.	2090-2120	637-646	62.	6650-6660	2027-2030
21.	2150-2180	655-665	63.	6670-6680	2033-2036
22.	2210-2240	674-683	64.	6690-6700	2039-2042
23.	2280-2310	695-704	65.	6710-6720	2045-2048
24.	2340-2370	713-722	66.	6730-6740	2051-2054
25.	2400-2450	732-747	67.	6750-6760	2057-2061
26.	2500-2550	762-777	68.	6770-6780	2064-2067
27.	2600-2650	793-808	69.	6790-6800	2070-2073
28.	2700-2750	823-838	70.	6810-6820	2076-2078
29.	2800-2850	853-869	71.	6830-6840	2082-2085
30.	2900-2950	884-899	72.	6850-6860	2088-2091
31.	3000-3050	914-930	73.	6870-6880	2094-2097
32.	3100-3150	945-960	74.	6890-6900	2100-2103
33.	3200-3250	975-991	75.	6906-6910	2105-2106
34.	3300-3350	1006-1021	76.	6920-6930	2109-2112
35.	3400-3450	1036-1052	77.	6940-6950	2115-2118
36.	3450-5535	1052-1687	78.	6960-6970	2121-2125
37.	5535-5567	1687-1697	79.	6980-6990	2128-2131
38.	5598-5629	1706-1716	80.	7000-7010	2134-2137
39.	5661-5691	1725-1735	81.	7020-7030	2140-2143
40.	5723-5762	1744-1756	82.	7040-7050	2146-2149
41.	5776-5806	1761-1770	83.	7060-7070	2152-2155
42.	5839-5869	1780-1789	84.	7080-7090	2158-2161

	Feet	Metres		Feet	Metres
85.	7100-7110	2164-2167	114.	7720-7730	2353-2356
86.	7120-7130	2170-2173	115.	7740-7750	2359-2362
87.	7140-7150	2176-2179	116.	7760-7770	2365-2368
88.	7160-7170	2182-2185	117.	7780-7790	2371-2374
89.	7180-7190	2189-2192	118.	7800-7810	2377-2381
90.	7200-7210	2195-2198	119.	7820-7830	2384-2387
91.	7220-7230	2201-2204	120.	7840-7850	2390-2393
92.	7240-7250	2207-2210	121.	7860-7870	2396-2399
93.	7260-7280	2213-2219	122.	7880-7890	2402-2405
94.	7300-7320	2225-2231	123.	7900-7910	2408-2411
95.	7340-7350	2237-2240	124.	7920-7930	2414-2417
96.	7360-7370	2243-2246	125.	7940-7950	2420-2423
97.	7380-7390	2249-2253	126.	7960-7970	2426-2429
98.	7400-7410	2256-2259	127.	7980-7990	2432-2435
99.	7420-7430	2262-2265	128.	8000-8010	2438-2442
100.	7440-7450	2268-2271	129.	8020-8030	2445-2448
101.	7460-7470	2274-2277	130.	8040-8050	2451-2454
102.	7480-7490	2280-2283	131.	8060-8070	2457-2460
103.	7500-7510	2286-2289	132.	8080-8090	2463-2466
104.	7520-7530	2292-2295	133.	8100-8110	2469-2472
105.	7540-7550	2298-2301	134.	8120-8130	2475-2478
106.	7560-7570	2304-2307	135.	8140-8150	2481-2484
107.	7580-7590	2310-2313	136.	8160-8170	2487-2490
108.	7600-7610	2317-2320	137.	8180-8190	2493-2496
109.	7620-7630	2323-2326	138.	8210-8220	2502-2505
110.	7640-7650	2329-2332	139.	8230-8240	2509-2512
111.	7660-7670	2335-2338	140.	8250-8260	2515-2518
112.	7680-7690	2341-2344	141.	8270-8280	2521-2524
113.	7700-7710	2347-2350	142.	8290-8300	2527-2530

PLATE 10.1

Figures 1-3. *Trochammina inflata* (Montagu)

1, 2. GSC 94368, hypotype, spiral view showing smooth surface, x204; and umbilical view showing depressed sutures, x210. Both from Harlequin D-86, 701-716 m.

3. GSC 94369, edge view of compressed test, x250. Harlequin D-86, 701-716 m.

Figures 4, 5, 7, 8. *Haplophragmoides* cf. *H. advenum* Cushman

4, 5. GSC 94370, hypotype, side view showing coarsely textured surface, x200; and edge view, showing slitted aperture, x270. Both from Osprey D-36, 1691-1715 m.

7, 8. GSC 94371, large hypotype, edge view illustrating compressed test and planispiral chamber arrangement, x111; and side view, x30. Both from Osprey D-36, 1917-1920 m.

Figures 6, 9. *Quinqueloculina akneriana* d'Orbigny

6, 9. GSC 94372, hypotype, apertural view, x76; and side view, x76. Both from Osprey D-36, 296 m.

PLATE 10.2

Figures 1, 2. *Pyrgo* cf. *P. williamsoni* (Silvestri)

1, 2. GSC 94373, hypotype, view of test face, x75; and edge view, x80. Both from Osprey D-36, 341-354 m.

Figures 3, 6. *Nodosaria incerta* Neugeboren

3, 6. GSC 94374, elongate hypotype, apertural view showing radiate aperture and circular section, x84; and side view, x65. Both from Harlequin D-86, 2290-2296 m.

Figures 4, 5. *Lenticulina inornata* (d'Orbigny)

4, 5. GSC 94375, hypotype, side view showing curved sutures, x240; and apertural view showing radiate aperture, x290. Both from Osprey D-36, 1780-1789 m.

Figures 7, 8. *Lenticulina nikobarensis* (Schwager)

7, 8. GSC 94376, hypotype, side view, x200; and apertural view, x 210. Both from Osprey D-36, 2082-2085 m.

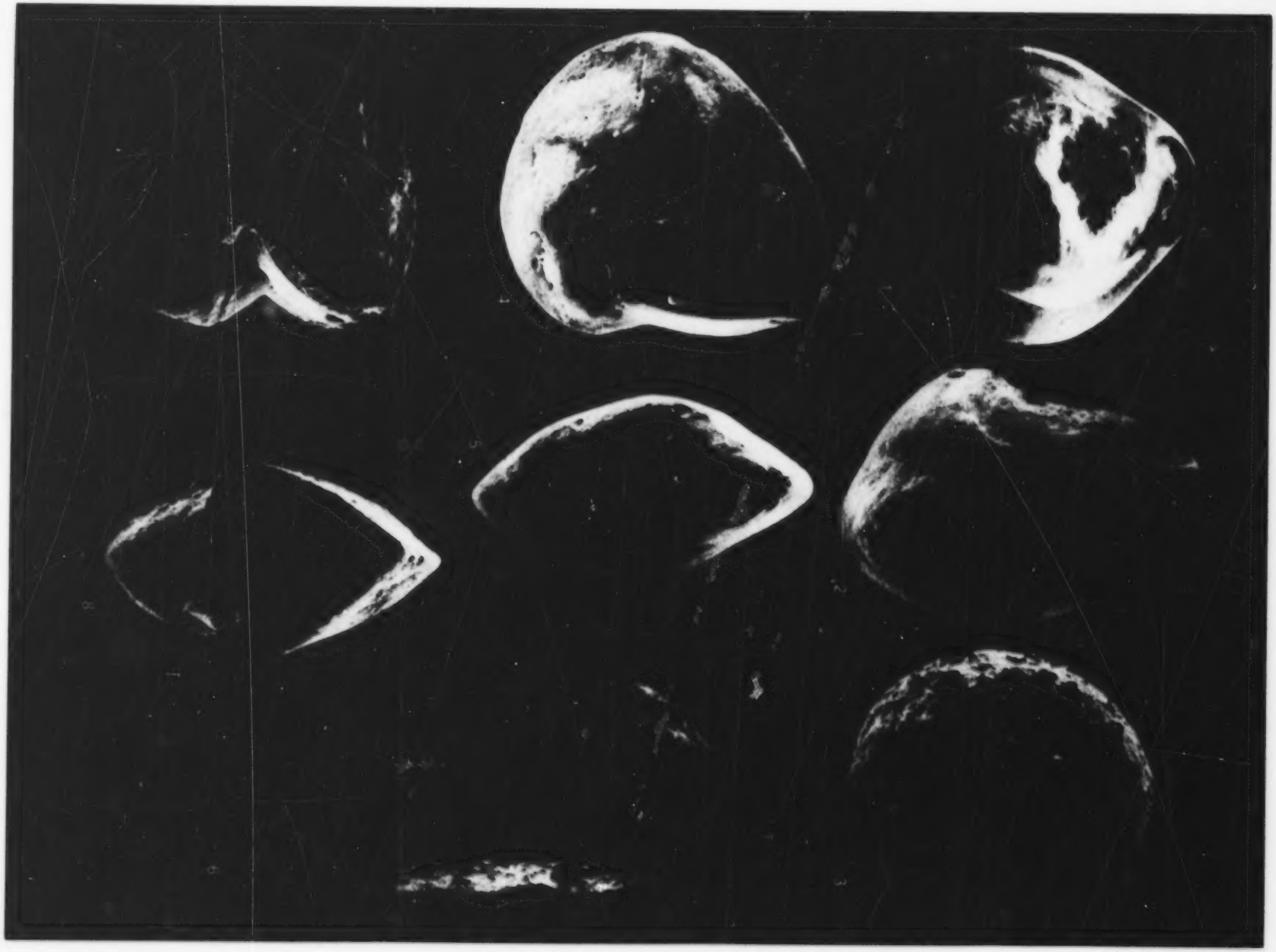

PLATE 10.3

Figures 1, 2. *Angulogerina fluens* Todd

1, 2. GSC 94377, elongate hypotype, apertural view showing trigonal section, x250; and side view, x210. Both from Harlequin D-86, 385 m.

Figures 3-5. *Euuvigerina juncea* (Cushman and Todd)

3. GSC 94378, elongate hypotype, side view showing almost uniserial arrangement of final chambers, x130. Osprey D-36, 399-408 m.

4, 5. GSC 94379, elongate hypotype, apertural view showing rounded cross-section, x210; and side view, x150. Both from Harlequin D-86, 1189-1204 m.

Figures 6-9. *Uvigerinella ornata* (Cushman)

6, 7. GSC 94380, hypotype, side view, showing faint longitudinal costae, x230; and apertural view showing subtrigonal cross-section, x310. Both from Osprey D-36, 2219-2387 m.

8, 9. GSC 94381, hypotype, side view with slightly recrystallized surface, x350; and apertural view, x350. Both from Osprey D-36, 2304-2307 m.

Figure 10. *Praeglobobulimina pyrula* (d'Orbigny)

GSC 94382, subglobular hypotype, side view, x140. Osprey D-36, 914-930 m.

Figure 11. *Buliminella elegantissima* (d'Orbigny)

GSC 94383, elongate, slightly damaged hypotype, side view, x330. Osprey D-36, 884-899 m.

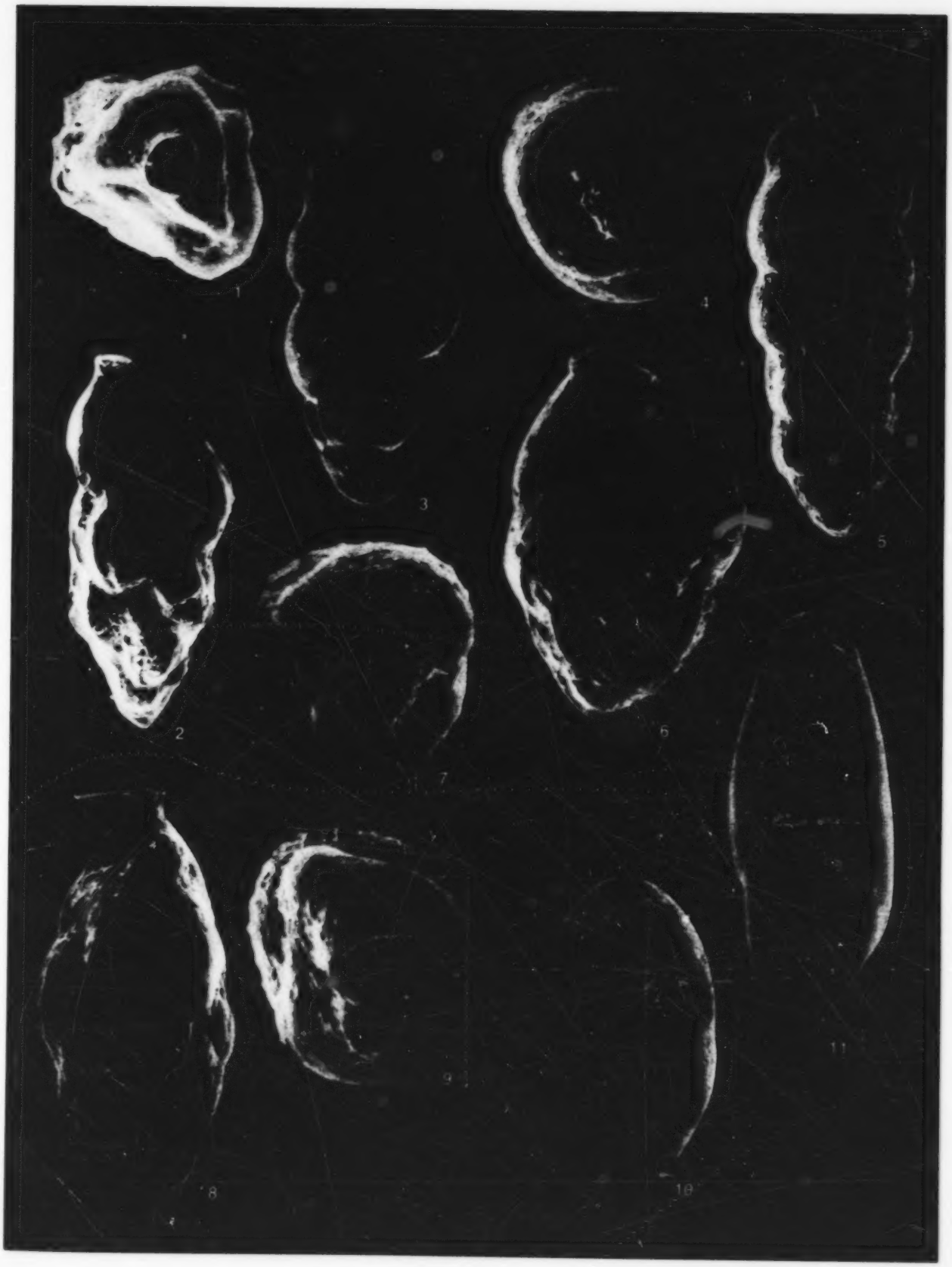
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PLATE 10.4

Figures 1, 2. *Transversigerina transversa* (Cushman)

1, 2. GSC 94384, hypotype, side view showing distinctive longitudinal costae, x62; and apertural view, x121. Both from Osprey D-36, 1051-1697 m.

Figures 3, 6. *Polymorphina*? sp.

3, 6. GSC 94385, hypotype, apertural view showing compressed test and radiate aperture, x300; and side view, x200. Both from Osprey D-36, 2207-2210 m.

Figure 4. *Homalohedra* cf. *H. apiopleura* (Loeblich and Tappan)

GSC 94386, hypotype, side view, x400. Osprey D-36, 1936-1939 m.

Figure 5. *Lagena striata* (d'Orbigny)

GSC 94387, hypotype, side view showing numerous longitudinal costae, x260. Harlequin D-86, 1714-1725 m.

Figure 7. *Homalohedra borealis* (Loeblich and Tappan)

GSC 94388, damaged hypotype, side view, x250. Harlequin D-86, 3002-3005 m.

Figure 8. *Procerolagena distoma* (Parker and Jones)

GSC 94389, typical slender hypotype, side view showing longitudinal costae, x140. Murrelet L-15, 329-337 m.

Figure 9. *Galwayella trigonelliptica* (Balkwill and Millett)

GSC 94390, hypotype, side view showing marginal carinae, x270. Harlequin D-86, 2634-2637 m.

PLATE 10.5

Figures 1, 2. *Buliminella curta* Cushman

1, 2. GSC 94391, elongate hypotype, side view, x190; and apertural view, x320. Both from Osprey D-36, 853-869 m.

Figure 3. *Islandiella limbata* (Cushman and Hughes)

GSC 94392, corroded hypotype, side view, x240. Harlequin D-86, 457-472 m.

Figure 4. *Cassidulina teretis* Tappan

GSC 94393, smooth hypotype, side view, x120. Osprey D-36, 296 m.

Figure 5. *Islandiella islandica* (Nørvang)

GSC 94394, subglobular hypotype with typical projecting apertural tooth, side view, x67. Osprey D-36, 0.3-296 m.

Figures 6-9. *Glabratella ornatissima* (Cushman)

6-8. GSC 94395, hypotype, view of smooth spiral side, x120; umbilical view of same gamont showing central area digested by escaping offspring, x103; and edge view, x140. All from Harlequin D-86, 457-472 m.

9. GSC 94396, agamont hypotype, umbilical view, x130. Harlequin D-86, 362-372 m.

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PLATE 10.6

Figures 1-3. *Epistominella pacifica* (Cushman)

1-3. GSC 94397, hypotype, edge view showing flattened spiral side and incised apertural region, x250; spiral view, x210; and ventral view, x210. All from Osprey D-36, 323-332 m.

Figures 4-6. *Baggina robusta* Kleinpell

4-6. GSC 94398, hypotype, spiral view showing rapid increase in size of later chambers, x126; umbilical view showing depressed sutures, x126; and edge view showing finely perforate surface, x150. All from Osprey D-36, 1827-1837 m.

Figures 7-9. *Valvulineria* sp. 1

7-9. GSC 94399, damaged hypotype, spiral view, x210; edge view showing foramen of penultimate chamber, x300; umbilical view showing incised sutures, x190. All from Osprey D-36, 1780-1789 m.

PLATE 10.7

Figures 1-3. *Buccella inusitata* Andersen

1-3. GSC 94400, hypotype, view of smooth spiral surface, x170; umbilical view showing numerous chambers and depressed sutures filled with papillae, x150; and edge view showing sharply carinate margin, x 103. All from Osprey D-36, 2194-2198 m.

Figures 4-6. *Buccella frigida* (Cushman)

4-6. GSC 94401, hypotype, spiral view showing slightly lobulate margin, x260; umbilical view showing deeply incised, papillae-filled sutures, x260; and edge view showing rounded periphery, x300. All from Osprey D-36, 418-427 m.

Figures 7-9. *Lobatula fletcheri* (Galloway and Wissler)

7-9. GSC 94402, compressed hypotype, umbilical view, x260; edge view, x260; and view of flattened spiral side, x260. All from Osprey D-36, 0.3-296 m.

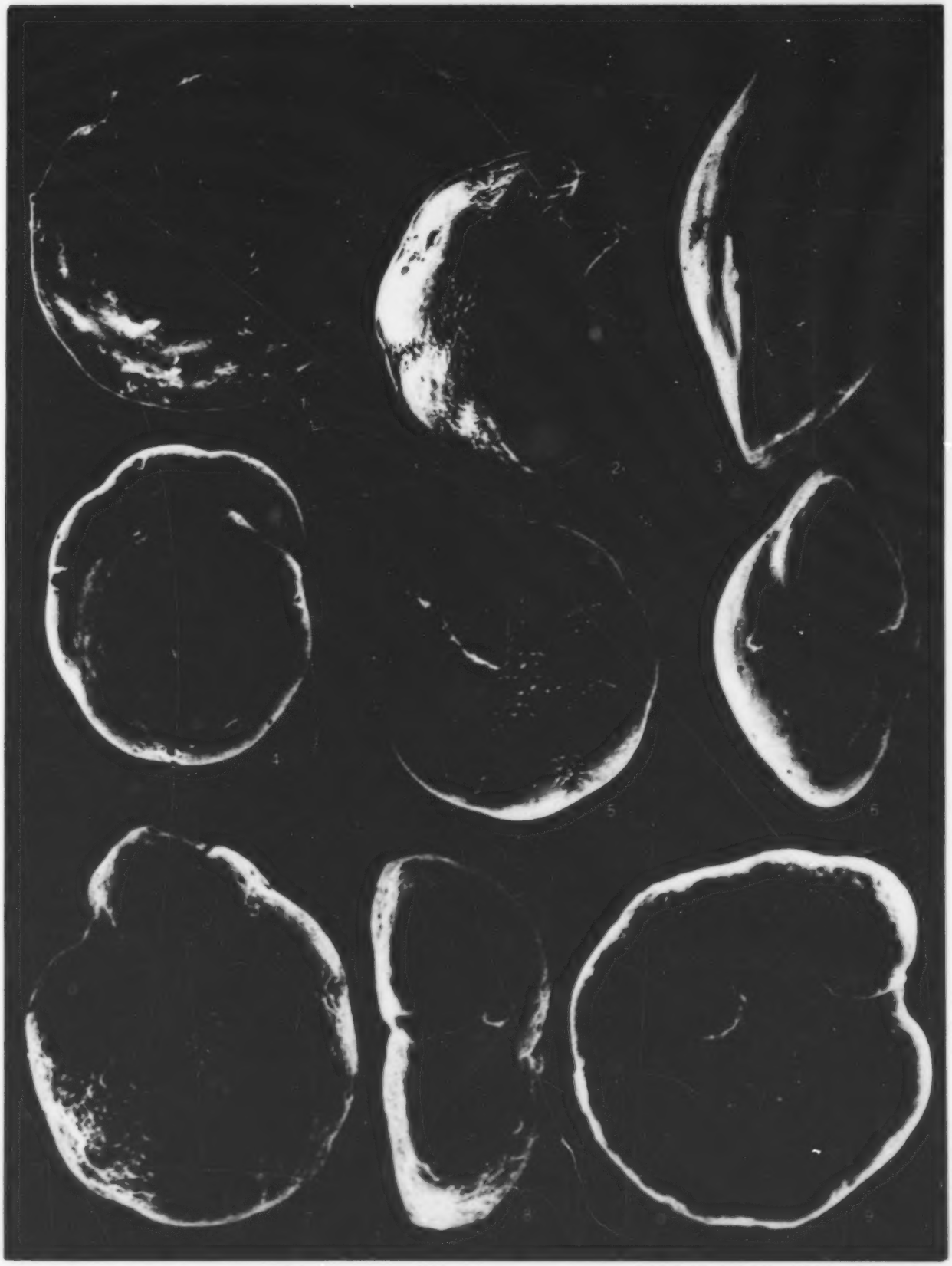


PLATE 10.8

Figures 1, 2. *Planulina* sp. 1

1, 2. GSC 94403, damaged hypotype, side view showing raised sutures, x310; and edge view showing compressed test and foramen of penultimate chamber, x102. Both from Osprey D-36, 418-427 m.

Figures 3, 4. *Melonis zandami* (van Voorthuysen)

3, 4. GSC 94404, damaged hypotype, side view showing coarsely perforate surface, x250; apertural view showing small, rounded basal foramen of penultimate chamber, x250. Both from Osprey D-36, 975-991 m.

Figures 5, 6. *Pullenia salisburyi* Stewart and Stewart

5, 6. GSC 94405, hypotype, side view, x310; and apertural view showing small basal foramen of penultimate chamber, x310. Both from Osprey D-36, 399-408 m.

Figures 7-10. *Bolivina arvena* Cushman

7, 8. GSC 94406, coarsely perforate hypotype, side view showing prominent reentrants along basal sutures, x250; and apertural view showing compressed test, x400. Both from Osprey D-36, 1051-1697 m.

9, 10. GSC 94407, hypotype, side view showing numerous anastomosing longitudinal costae, x210; and apertural view showing elongate aperture, x400. Both from Osprey D-36, 1051-1697 m.

Figures 11-13. *Nonionella miocenica* Cushman

11-13. GSC 94408, umbilical view showing extension of final chamber covering umbilicus, x150; spiral view, x350; and apertural view, x175. All from Harlequin D-86, 2515-2518 m.

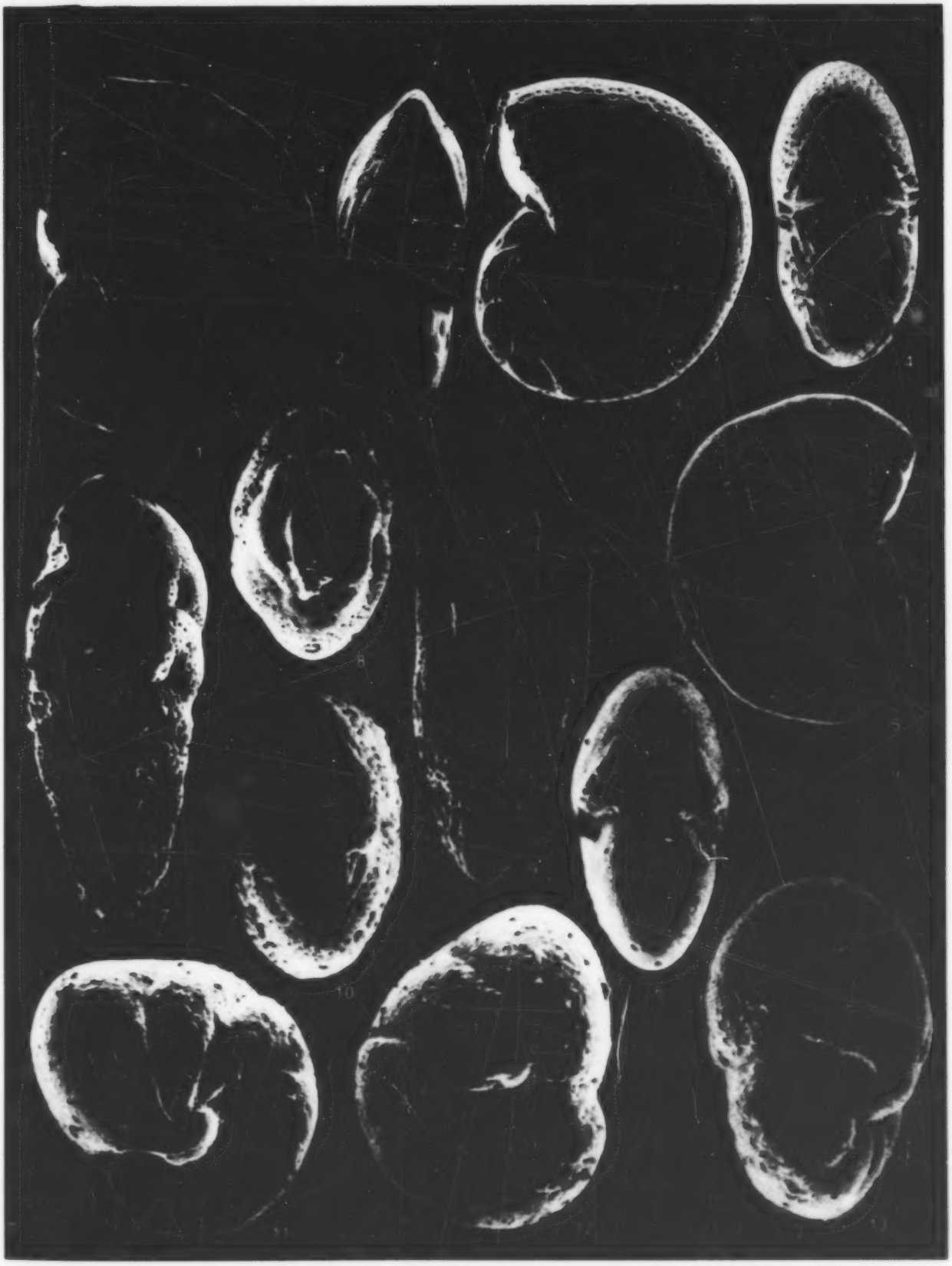


PLATE 10.9

Figures 1-3. *Nonionella davanaensis* (Pierce)

1-3. GSC 94409, hypotype, umbilical view, x240; spiral view, x350; and apertural view showing nearly planispiral chamber arrangement, x175. All from Osprey D-36, 637-646 m.

Figures 4-6. *Pseudononion costiferum* (Cushman)

4-6. GSC 94410, hypotype, side view showing numerous chambers of final whorl, x240; view of other side, x240; and apertural view showing planispiral arrangement, x230. All from Osprey D-36, 1051-1697 m.

Figures 7-9. *Cribroelphidium vulgare* (Voloshinova)

7-9. GSC 94411, hypotype, enlargement of hispid sutures, x520; side view showing inflated chambers, x100; and apertural view, x120. All from Harlequin D-86, 2576-2579 m.

PLATE 10.10

Figures 1, 2. *Cribroelphidium vulgare* (Voloshinova)

1, 2. GSC 94412, hypotype, side view, x150; and apertural view showing small elliptical aperture at base of last chamber, x150. Both from Harlequin D-86, 2576-2579 m.

Figure 3. *Elphidiella nitida* Cushman

GSC 94413, damaged hypotype, side view, x120. Osprey D-36, 0.3-296 m.

Figures 4-9. *Cribroelphidium excavatum* (Terquem)

4, 5. GSC 94416, finely perforate hypotype, side view showing distinct retral processes, x280; and apertural view, x310. Both from Osprey D-36, 323-332 m.

6, 9. GSC 94414, finely perforate hypotype, side view, x175; and apertural view, x170. Both from Osprey D-36, 399-408 m.

7, 8. GSC 94415, hypotype, side view showing distinct umbilical button, x280; and apertural view, x300. Both from Osprey D-36, 341-354 m.

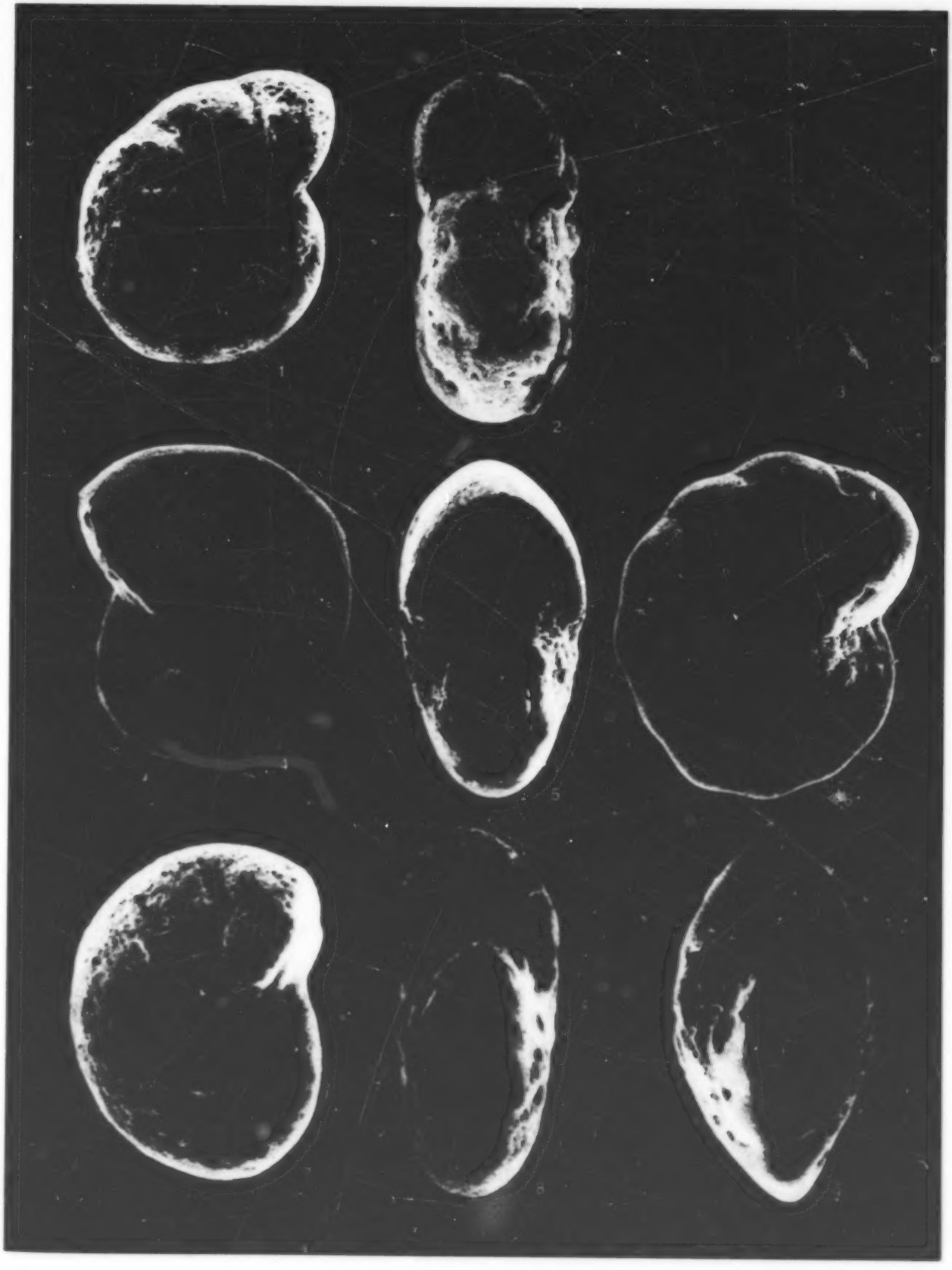


PLATE 10.11

Figures 1, 2. *Cribroelphidium excavatum* (Terquem)

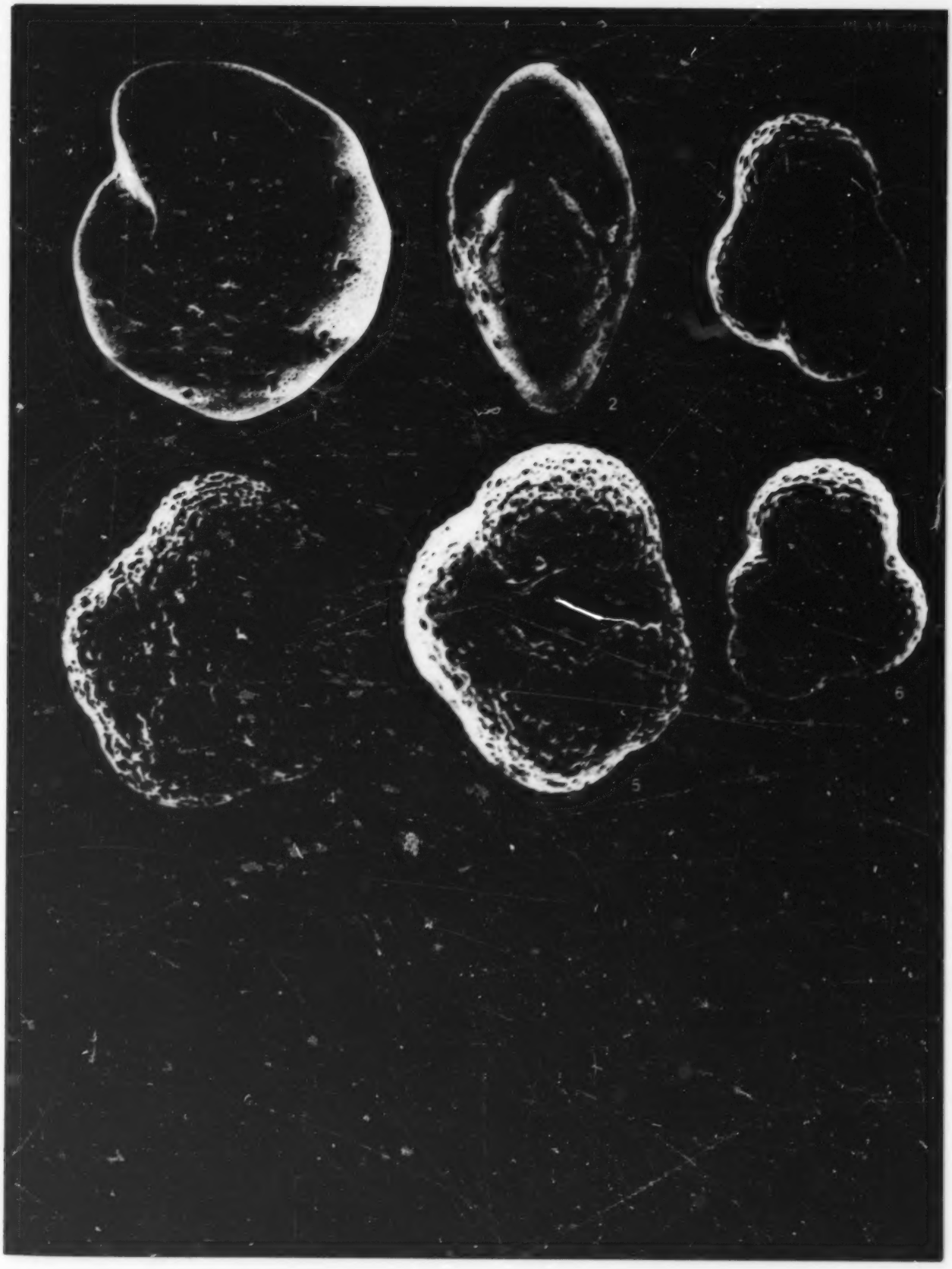
1, 2. GSC 94417, hypotype, side view, x210; and apertural view, x210. Both from Osprey D-36, 399-408 m.

Figures 4, 5. *Globigerina bulloides* d'Orbigny

4, 5. GSC 94419, finely perforate hypotype, spiral view, x270; and umbilical view, x270. Both from Osprey D-36, 399-408 m. (Specimen missing.)

Figures 3, 6. *Tinophodella glutinata* (Egger)

3, 6. GSC 94418, typical hispid hypotype, umbilical view, x200; and spiral view. Both from Osprey D-36, 341-354 m. (Specimen missing.)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